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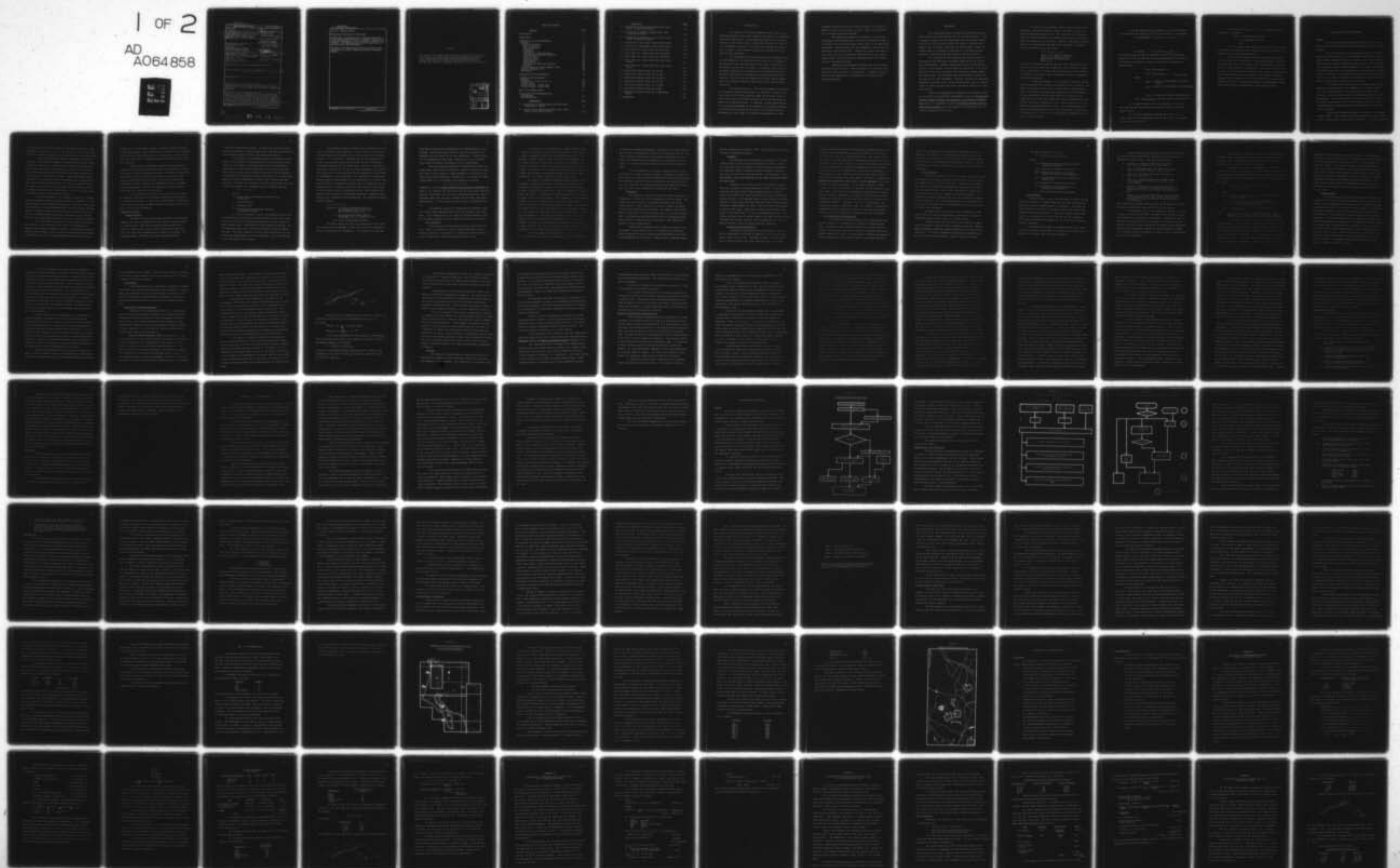

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At present, a number of separate maps, charts, and tables are required, and manual techniques are used to estimate construction effort and determine where facilities should be placed in an AOA. Present techniques are time consuming, which makes it difficult to optimize placement of facilities within operational constraints to minimize the construction effort and avoid — over

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Block 20. Abstract (Cont'd)

relocation of facilities at a later time.

A methodology is developed which is expected to reduce horizontal construction effort by 20%; included are depictions of significant attributes of terrain, facilities, and their interrelations. The methodology was successfully exercised in a near-operational, MAF-size example.

Automation of the methodology and of the construction effort computations to produce a computerized system is presently underway.

FOREWARD

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INTRODUCTION

The support of the Marine Amphibious Force (MAF) in an Amphibious Objective Area (AOA) requires development of an adequate logistics support base. During amphibious operations, the availability of construction forces to build the base will be limited. It is necessary, therefore, to minimize the construction requirement in order to meet scheduled operational readiness dates for high priority facilities.

The construction effort required for an individual facility will depend on the characteristics of the site it occupies in the objective area, and each facility will have a site where its construction effort will be minimal. In addition, there will be an optimal combination of sitings for all facilities within the objective area which will minimize the total construction effort required. Factors other than construction effort, such as operational requirements, should be taken into account when defining optimality.

The actual siting of a base and its component facilities is an iterative process which begins as a general overview of the entire AOA in the initial planning stages and proceeds to the selection of sites for specific facilities as part of the Engineer Annex to the Operations Plan. In addition, various modifications to the siting arrangement can be expected to be required to adjust to situations arising during the course of the actual operation. The purpose of this study is to develop and demonstrate a land

management technique which will enable planners to identify the optimal sitings for facilities in an AOA, taking into account a set of initially-specified factors.

The technique developed is described in the section, Development of the Methodology. It has been developed so that it is suitable for application using either manual or automated data processing. Manual methods have been employed to demonstrate the technique as described herein. Although not within the scope of this study, the use of automation would provide for processing larger amounts of data and permit consideration of more factors than can be handled manually.

Implementation procedures are provided in the section, Implementation Procedures. These procedures were applied to the siting of a MAF size base in a remote AOA. A report of the results of the demonstration is contained in the section, MAF - Size Demonstration.

BACKGROUND

The initial selection of potential locations for a proposed facility has traditionally been an intuitive process. A team of experts familiar with the operational and construction requirements of the facility would examine the region of interest and select a set of suitable locations for further study. These locations would be individually subjected to a detailed economic analysis to determine which site would be the most efficient.

The rationale for not subjecting all possible sites to this analysis was that such a procedure would be far too costly and time-consuming. However, because the initial section was intuitive, it was subject to such factors as variations in the availability of data within the region and individual personal experiences and biases. Two different teams were unlikely to arrive at the same set of final candidates. Moreover, factors not immediately reducible to monetary (i.e., dollar values) terms, such as environmental or social impacts, were either ignored or treated in a pass/fail fashion.

While giving quantitative evaluation of individual sites, the airfield siting procedures recommended in both the <u>Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations</u> (Ref. 10 in Appendix T) and the <u>Automated Procedure for Airfield Site Evaluation</u> (3) still require, as a first step, the intuitive selection of trial sites.

To overcome this potential initial biasing, modern land management techniques attempt to subject the entire region to a uniform, definable analysis (15). The first step is to determine those site characteristics or parameters which affect the desirability of locating at a given site. Second, a functional relationship (f) is defined which combines these parameters to indicate relative desirability (D) as follows:

$$D = f\ (p_1,\ p_2,\ \ldots.\ p_n)$$

where p is a specific parameter and n is the number of parameters used to determine the value of D

The area of interest is then divided into small sub-areas and the values of each parameter are assigned for each sub-area by inspection or measurement. Finally, the desirability for each sub-area is computed. The sub-area with the optimal D value is considered the most advantageous.

To apply the method, it is necessary to determine quantifiable parameters which affect the desirability of a location. The number of parameters which might be considered is usually quite large. Selection from among these parameters can be facilitated by first determining the principal factors of concern such as construction cost and time, operational cost, environmental acceptability, political acceptability, etc. Each of these in turn suggests which parameters should be used. Every attempt should be made to use parameters whose values can be measured in some objective fashion (i.e., the value of the parameters themselves are not open to interpretation).

It may be advantageous or necessary to use the parameters for each factor and determine a value for the factor. For example:

$$D\ \text{environmental} = f\ (p_1\ \text{envir.},\ p_2\ \text{envir.}\ \ldots)$$

.

.

.

$$D\ \text{economic} = f\ (p_1\ \text{econ.},\ p_2\ \text{econ.}\ \ldots)$$

The factor values can then be combined by use of an appropriate function to give the value for relative desirability, this function may consist of assigning a weight to each factor and adding the weight values:

$$D = R_{env.}\ D_{environmental} + R_{soc.}\ D_{sociological} + \ldots + R_{econ.}\ D_{econ.}$$

where:

$R_{env.}$ = weight for environmental considerations

$R_{soc.}$ = weight for sociological considerations

.
.
.

$R_{econ.}$ = weight for economic considerations

and $D_{environmental,}$ etc. are as previously defined

If a single value for D can be obtained for each sub-area then the sub-area with the best overall value would be the optimal choice.

If it is not possible to combine the factors into a single value then the optimization can be carried out by a process of elimination as follows:

All sub-areas with D_x ($x = 1, 2 \ldots$) values less than specified are rejected.

where 1 = environmental factors

2 = sociological factors

etc.

If two or more choices survive, the factors can be placed in priority order with the final choice being based on values assigned to the highest priority factors.

While the above process includes subjective decisions, such decisions must be expressed in quantitative terms. Therefore, the exact extent to which a decision has been affected by certain biases or preferences can be determined. The form of the function or value of the coefficients become the focal point in negotiations rather than abstract ideas or opinions. The effects of adverse opinions can be checked to see if any differences in final results actually do occur. In short, the proposed land management methodology makes siting a mathematically controllable function.

DESCRIPTION OF THE METHODOLOGY

General

The siting methodology developed in this study is based on the modern land management techniques described in the previous section.

The actual siting of the facilities comprising a Marine Amphibious Force (MAF) base in an Amphibious Objective Area (AOA) would involve consideration of many factors. These factors can be lumped into two groups; construction and operation. The construction objective function would be defined by the number of resource units which would have to be provided to construct a base or facility at a given time. The operation objective function would be defined as the number of resource units required to enable the base or facility to maintain a certain level of service.

To evaluate the relative merits of various cases, these resource units would have to be converted to a single denominator. For civilian purposes, the normal choice is money (i.e., dollars). For this study, however, a more appropriate unit would be man-days. If every operational and construction factor could be equated to man-days, then the site requiring the least number of man-days would represent the best choice from both a time and effort viewpoint.

Converting construction effort to man-days is a straightforward effort. Most estimation techniques assign man-days or man-hours to various tasks under various conditions. A completed project

at a given site represents the sum of the various individual tasks required to complete the project. By summing the man-days for each task, the required man-days for the entire project can be determined.

Converting operational effort to man-days is not always as direct. For instance, suppose a decision had to be made between building an airbase in a location where construction was easy but the weather poor (say a lowland near the beach) or in a location where construction was more difficult but the weather much better (say on top of a mountain well inland). The better weather means that, for a given period of time, the mountain base could generate more sorties than the lowland base. The siter must somehow weigh the value of these extra sorties against the extra effort required to construct the base on the mountain top. To do so, he must somehow convert sorties into equivalent man-days.

To further complicate the problem, the value of a man-day during an operation usually depends on when it is expended. In the initial phases of most amphibious operations, there is a restriction on the numbers of men and equipment which can be put ashore and supported. A man-day during this period is more critical to the success of an operation than during later periods when the beachhead areas have been expanded and the supply system is operating smoothly.

This time factor accounts for the fact that the construction quality of most facilities built early in an operation is generally below normal standards. Quality is sacrificed to conserve valuable early man-days. Those early facilities which must continue to function for more than a short period of time generally require

a higher level of maintenance effort or must be rebuilt to correct initial deficiencies. This maintenance or corrective action requires man-effort and inhibits operations. In such cases, a trade-off has been made, consciously or unconsciously, between construction effort and operations.

Optimizing such trade-offs required deriving objective functions for important operational factors and developing a scheme to compare resource expenditures occurring at different time periods. This complex problem is outside the scope of the present study. Only the construction effort aspects of the siting problem are considered in detail, although any operational factors involving spatial requirements, such as safe separation distances between facilities, are also taken into account.

The technique herein can be used in any situation where an objective function can be developed to express the desirability of individual locations. In the future, operational considerations can be included without any modifications to the basic siting technique which has been developed.

Construction Effort

General Equation

To apply the basic methodology described in the previous chapter, the person responsible for siting must be able to assign to each sub-area a value which represents the desirability in regard to constructing a certain type of facility at that location. For this study, desirability is taken to be minimum construction effort. Therefore, the value assigned should be

a measure of construction effort. To obtain this value the siter must have available a function which will relate the characteristics of the facility and the site to the construction effort.

As discussed in the previous chapter, the number of parameters which measures the characteristics of the site may be quite large, and the selection from among them would be facilitated by identifying the main factors which affect the construction effort. These factors in the case of construction effort, are the specific construction tasks which are directly influenced by site conditions, namely: clearing; earthmoving or grading; and providing adequate drainage. Following this rationale, a general relationship for site-related construction of a particular type of facility would be:

$$CE = C + G + D$$

where:

CE = Total construction effort related to site conditions

C = clearing effort

G = grading effort

D = drainage effort (sometimes combined with grading effort)

It is still necessary to select the parameters to be used in estimating the construction effort involved in each of the parameters and their use in estimating construction effort involved in each of these tasks. The selection of the parameters and their use in estimating construction effort are described in the following sections. There are, however, two other factors which must be considered and incorporated in the basic equation. They are discussed in the remainder of this section.

The preceding equation considers only construction effort that is related to site conditions. In some cases, several types of facilities may be available for use for a particular functional purpose. It is necessary , therefore, to have the capability to select from among the types of facilities, as well as providing the optimal location for the chosen type. The total construction effort for each facility is made up of two components; the construction effort which is site-related and the construction effort which is independent of site conditions. The variations in construction effort resulting from changes in site conditions may be larger than the differences in construction effort that are independent of site considerations. Therefore, selections from among the types should be on the basis of total construction effort. This requires that another term be added to the preceding equation to represent work which is not a function of site conditions. The construction effort equation becomes:

$$CE = C + G + D + X$$

where CE = the total construction effort in an appropriate unit such as man-days, battalion-days, etc.

X = the construction effort which is independent of site conditions, and

C, G, D are as previously defined.

In certain cases, the type of facility which can be used at a certain site is dependent on the values which are assigned to the site characteristics' parameters. For instance, the type and

thickness of paving can be affected by the characteristics of the subgrade. This would require that the value of X assigned vary depending upon the values of the site parameters. A single value for X was employed in this study. However, the use of multiple values could be readily incorporated into the methodology.

The last equation represents the construction effort required under normal working conditions. However, construction work done close to battle areas is often hampered by such things as fatigue, poor living conditions, sabotage, etc. To account for these, a delay factor (E) is included in the equation as follows:

$$CE = (C + G + D + X)\ E$$

Paragraph 4.3 of the Seabee Planner's and Estimator's Handbook (Apendix T, 11) indicates how the value of E for a particular operation should be calculated. The value of E ordinarily would not vary for different sites, but would be a constant for the whole area under consideration. For the purposes of this study, E is assumed to be 1.0.

A multiplier similar to E could also be included to take into account items affecting work effort not covered in the handbook. In the demonstration, the effect of distance between a base and its nearest supply point was handled using such a multiplier.

Site Paremeters

Three broad site characteristics affect construction effort. These are vegetation covering, terrain geometry, and geotechnical features. Any estimate of construction effort should, at a bare minimum, take these characteristics into account.

In general, it is not possible to assign an exact value to a particular parameter within a given land area. One reason is that the parameter value has to be estimated from maps or photographs. Another reason is that the value of the parameter usually varies within the land block. To avoid these problems, the range of all possible values for a particular parameter is subdivided. For instance, soil thickness can be classified as thick, average, and thin with thick meaning greater than 20 feet, average meaning 2 to 20 feet, and thin for less than 2 feet.

The number of discrete construction effort values to be calculated is equal to the number of sub-divisions within each parameter all multiplied together. For instance, if there were a parameter describing vegetation with three (3) subdivisions (bare, brush, and forest), a parameter for topography with three (3) subdivisions (flat, hilly, and rough), and a parameter for geotechnical features with two (2) subdivisions (good, bad), there would be 3x3x2 = 18 possible combinations of parameter values. The construction effort value for each combination must be calculated. Therefore, the number of construction effort values which must be calculated is dependent on the number of parameters being used and the number of subdivisions within each parameter. As will be demonstrated, the amount of work necessary to prepare a Terrain Characteristics Pamphlet (TCP) prior to doing the actual siting is directly proportional to the number of possible parameter combinations.

On the other hand, the accuracy of the estimation is also a function of the number of parameters and the differentiation

of values for a specific parameter. Essentially, the more detailed the available information is, the better the estimate will be. The problem becomes selecting the best possible combination of parameters and subdividing those parameters in such fashion so as to achieve the desired predictive accuracy with the least amount of work.

For the purposes of this study, parameters were selected based on a similar estimation process in Reference 10 which also used parameters, and on civilian construction estimating techniques. The parameters selected were not subjected to any stringent tests to see if they were the optimum choices for the purposes for which they were used. The following site parameters were used:

Vegetation

The parameters chosen to reflect the extent and type of vegetation in a given area is a description of the situation. The encoder is given a choice of descriptive phrases (e.g., bare, brush, forest). After observing the area, he chooses the phrase he feels best describes the situation. The number of descriptive phrases range from 3 for less accurate work to 5 for more accurate work. Man-made structures which would have to be demolished were accounted for as special types of vegetation. This approach is similar to that in Reference 10.

Quantitative parameters such as stem count density (i.e. the number of stems greater than 2" in diameter per 1000 square yards) could also be used if data exists (photographs) from which such information can be derived. However, such an approach would

greatly complicate the encoder's task. Such parameters are better suited for automated techniques.

Roughness

The parameter used to describe the geometry of the land surface within a given area proved difficult to select. Along any given base line, the terrain can have different longitudinal and transverse slopes. Moreover, several different situations can occur over the size of the areas used. For instance, in desert country, a flat area could be cut by a deep ravine with nearly vertical sides.

Reference 10's attempt to solve this problem involved defining a parameter called characteristic slope. Characteristic slope was the worst general slope appearing within the area. Slopes were divided into those less than 2%, 2%-10%, 10%-30% and greater than 30%. This approach seems to work very well when the encoder is using large scale maps subdivided into relatively small land areas (approximately 25 acres). But, for large subdivisions or smaller scale maps, a descriptive system (flat, hilly, rough) seems to work much better. In using the descriptive system, the encoder not only looks at contour spacing, but also examines contour curvature and cultural features, such as road alignment, to get a general feeling of what the terrain actually looks like.

Geotechnical Characteristics

Geotechnical characteristics are described by a parameter or parameters reflecting the make-up of the foundation material within a given area. Reference 10 used 3 different parameters (soil thickness, soil type, and rock type). The first

trials of the siting technique utilized these parameters with 3 subdivisions for soil thickness (greater than 20 feet, 2 to 20 feet, and less than 2 feet), 4 subdivisions for soil type (gravel, sand, low plastic clay, and high plastic clay/organic material) and 2 subdivisions for rock (soft and hard). Use of these parameters required that the encoder have a technical background in geology and soils engineering as well as photographic interpretation experience. Effort gained from such a detailed analysis of geotechnical factors was not considered worth the extra effort. Therefore, a descriptive approach was adopted for latter work. In this approach, the encoder examines the area in question. If any bogs, lowlands, running streams, or canals are present, he considers the geotechnical conditions "bad". If none of the aforementioned conditions are evident, the soil is good. However, if the edges of rock outcrops or other evidence of rock close to the surface are visible, the area is considered "good-thins". Otherwise, the area is "good-thick". Although this method is admittedly crude, the effects of geotechnical characteristics on construction effort are not great enough when compared with other parameters to warrant additional refinement.

Construction Task Relationships

The construction effort required for a construction task such as grading is the product of the quantity of work required (e.g., thousands of cubic yards of material to be moved) and the man-day effort required per unit of work (e.g. man-days/1000 cubic yards of material to move). For each type of facility, the quantity of work required will be a function both of the parameters which

measure site conditions and the physical characteristics of the facility. The estimates of man-day effort required per unit of work also are dependent on site conditions (e.g., type of material to be moved) but are independent of the type of facility. The relationships developed for each task are discussed in the following paragraphs.

Clearing Effort

The clearing effort (C^f) for a facility includes the tasks of clearing and stripping (removing the top layer of soil containing organic material) areas as required. Clearing and stripping are done for such reasons as construction, security, fire prevention, and pest control. Each facility has specific requirements as to how much area must be cleared and how much stripped. As roughness of terrain increases, the area to be cleared or stripped may also increase. This is primarily because, as the heights of cuts or fills increase, the old surface area that must be cut away or covered also increases.

The work effort per unit area (e.g., man-days per 1000 square feet) for clearing is primarily a function of the type of vegetation (grass, brush, trees, etc.) being cleared.

The work effort per unit area to strip and cast organic material would be a function of the material's thickness. However, normal estimation techniques assume thickness to be a function of vegetation. C^f is thus a function of the type of proposed facility, the site's terrain roughness, and the vegetation present.

The general equation for C^f is:

$$C^f = A_c^f R_g^f U_v + A_s^f R_g^f t_v U_s$$

where:

C^f = construction effort to clear and strip land for a facility

A_c^f = cleared area required for facility

R_g^f = roughness multiplier for facility located on terrain with roughness g

U_v = unit work effort to clear a particular vegetation v

A_s^f = stripped area required for facility

t_v = thickness to be stripped based on presence of vegetation v

U_s = unit work effort to strip and cast

Grading Effort

Most facilities require that the ground on which they are located be graded to a desired shape (and the soil treated to improve its strength characteristics, if required). The amount of earth which must be moved is a function of the final shape of the ground at the proposed location. Thus, the quantity of material (Q_g^f) is a function of the type of facility and the roughness. Q_g^f usually represents the quantity of cut or fill in a balanced cut/fill situation.

The construction effort for grading is not only a function of the quantity of material to be moved, but also the type of material, its source, and its final destination.

Common construction estimating practice divides Q_g^f into six separate classifications and multiples each sub-quantity by a different unit work effort. The classifications are:

a. Common (m) - material which can be excavated and moved by a machine in a single pass;

b. Rip (p) - material which must first be loosened with a ripper tooth before it can be moved;

c. Blast (b) - material which must be blasted before it can be moved;

d. Spoil (l) - material which must be dumped away from the work site because it is either excess or unsuitable;

e. Fill (f) - common, rip or blast material which is moved from its point of excavation directly to another point on the site, placed, and compacted; and

f. Borrow (u) - material which must be excavated off-site and hauled to the site, placed, and compacted to supplement existing material or replace unsuitable material.

Spoil and borrow unit work effort values include work done to haul the material between the site and the dump or borrow pit.

The percentage of Q_g^f to be assigned as common, rip, etc., is derived through the intuitive judgement of the estimator, based on availability of geotechnical information. Percentages vary from facility to facility based on such factors as whether or not the facility lies on the top of the ground or requires deep foundations. The sum of the percentages assigned to the cut materials (common, rip, and blast) equals 100 percent, as does the sum of those assigned to the fill materials.

If an unsuitable material is present, the estimator may decide to remove and replace more earth than is predicted by Q_g^f. In such a case, the percentages of Q_g^f assigned to the various categories could total to more than 100 percent.

In summary, the value of the grading effort (G^f) is a function of the type of facility, the site's terrain roughness, and those geotechnical parameters which enable the estimator to predict by percentages the type of material to be handled. The equation is as follows:

$$G^f = Q_g^f \, (p_m^f \, U_m^f + p_p^f \, U_p + p_b^f \, U_b + p_l^f \, U_l + p_f^f \, U_f + p_u^f \, U_u)$$

where:

Q_g^f = quantity of cut or fill for a facility on terrain with roughness - g.

p_x^f; x = m, p, b, l, f, or u - percentage of Q_g^f assigned to material for a facility on terrain with roughness - g.

U_x, x = m, p, b, l, f, or u - Unit work effort for material x.

NOTE: The values of U_l and U_u could be considered site-dependent due to associated haul distances. However, in this study, a 1 mile haul is automatically assumed.

It should be noted that it would be possible to compute equipment-days as well as man-days using the same technique. For instance, to excavate 1,000 cubic yards of material from a borrow pit, haul it one mile, and spread, sprinkle, and compact it requires 13.0 man-days (Appendix T, 11). The work crew and equipment required is 10 men, 1 front end loader, 5 dump trucks, 1 water truck, 1 grader and 1 compactor. Therefore, it would be possible

to say that it takes a crew 1.3 days to excavate, move, and place 1,000 cubic yards of borrow, or 1.3 loader-days, 6.5 dump-truck-days, 1.3 water-truck-days, 1.3 grader-days, and 1.3 compactor-days per 1000 cubic yards. From this information, the individual equipment-type CE could be computed. This information (broken down by task) could be input into scheduling programs similar to the ones utilized by Springston (Appendix T, 12) in his report to establish scheduling priorities and indicate potential bottlenecks. Such an effort would require extensive bookkeeping and cross-referencing and does not lend itself to the type of manual approach envisioned in this study.

Drainage Effort

The construction effort required to provide drainage for a facility (D^f) involves providing suitable protection against the effects of subsurface water and storm run-off. The degree and type of protection required is a function of the facility. The specific treatments necessary to achieve the required level of protection are functions of site hydrologic characteristics and design storm intensity. The site parameters chosen to represent the site hydrologic characteristics are roughness and geotechnical characteristics. If the area under consideration was extensive or contained features that significantly affect meteorological conditions, design storm intensity could vary as a function of location. Under normal circumstances (and for this study), storm intensity could be assumed to be a constant. The maximum design storm intensity for this study is 1 inch of rainfall per hour.

All fills (including berm walls) and the subgrades of load-bearing surfaces should be protected from ground water because the water decreases the bearing strength of the material and significantly accelerates surface distortions by causing slope failures, pot holes, soft spots, and frost heave. Certain materials such as clays are especially affected and protection for facilities located on these materials must be extensive. For the purposes of this study, ground water is treated by placing a blanket of select gravel between the old surface and the fill or subgrade. This blanket intercepts water seeping out of the old ground and carries it away before it can soak into the subgrade material. The blanket also drains away any water soaking into the subgrade from the surface due to precipitation.

Surface run-off must be eliminated in a safe manner to avoid overtopping or eroding the facility's earth structures. Elimination must be done as quickly as possible to avoid interference with operations due to flooding and to avoid saturating the foundation material, causing problems mentioned earlier. For each facility except highways, a typical network of ditches and culverts depends primarily on the slope of the terrain and the design storm intensity. Whether or not riprap protection must be provided for individual ditches is a function of the calculated flow velocity in the ditch and the erosion characteristics of the soil.

Erosion characteristics may also dictate the number and shape of erosion channels likely to be encountered by linear facilities such as highways and, hence, the estimated number of culverts

to be provided per unit length. For this study, however, the number of culverts per unit length of highway was considered to be solely a function of terrain roughness.

Fixed Effort

As mentioned previously, fixed work is defined as construction effort not significantly affected by site parameters. For example, the placement of the final base course and paving of each pad in an ammunition revetment would be considered as fixed work since the size of the pad is a function of the revetment design only.

Estimates of Construction Effort

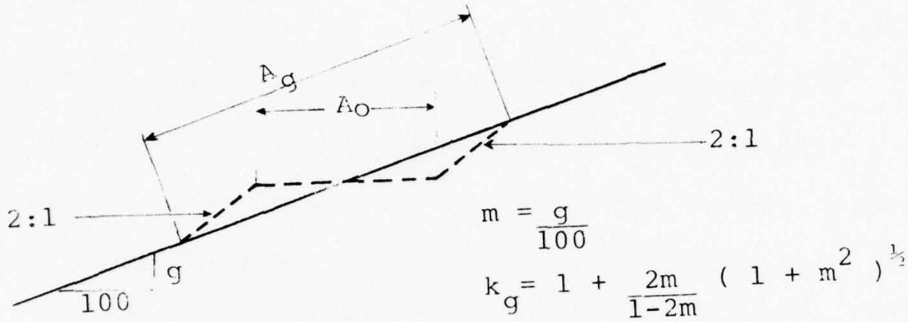
Estimates of the construction effort for a construction task using the relationships discussed in the foregoing requires estimates both of the quantities of work and man-day effort per unit of work. Unit man-day quantities can be assigned to each combination of parameter values using generally accepted industry or other standards. For this study unit man-day estimates were obtained from reference in Appendix T, 1.

The unit man-day estimates used must be based on a set of assumptions as to the number and type of personnel and equipment which will accomplish the construction. These assumptions are applied uniformly to the entire area under consideration. The construction effort estimates obtained in this matter are adequate for comparing the desirability of individual sites. However, as the planning proceeds it may become apparent that the construction work will be carried out under actual conditions which are different

from the assumptions used. For instance, self propelled scrapers may not be available for earthmoving as assumed, or trucks may be limited to sizes other than those on which the unit man-day estimates are based. Therefore, before the construction estimates are used for manpower or equipment requirements planning, it will be necessary to insure that the unit man-day estimates which are used agree with the actual conditions under which the work will be done.

The quantity of work needed for a task does not vary independently with either the physical characteristics of the facility or the site conditions but depends on the relationships that exist between the various parameters which measure each. These relationships may take the form of a single mathematical formula. If the interactions between the variables are too complex to permit derivations of a single formula the estimates can be made by completing a series of calculations for each set of parameter values. The time and effort required for calculation of the values will depend on the difficulty encountered in analyzing the relationship between the facility characteristics and the site conditions.

As an example, a typical relationship which applies to many different facilities is the relationship between the amount of area which must be cleared on sloping ground to permit construction of a horizontal pad and the slope of the ground. If it is assumed that the ground slopes in only one direction, that the pad is to be constructed transverse to the slope, that the cut and fill is to be balanced and that both cut and fill will stand at a 2 to 1 slope, then the problem can be analyzed using the following diagram.



Referring to the diagram, what is desired is a factor, K_g, by which the value for A_o can be multiplied to give A_g, i.e., $A_g = K_g A_o$.

Letting $m = \frac{g}{100}$ = percent grades

Then $K_g = 1 + \frac{2m}{1-2m} (1 + m^2)^{1/2}$

If the only requirement for the facility is construction if the horizontal pad then K_g can be used for the value for R_g^f in the general equation for clearing:

$$C^f = A_c^f R_g^f U_v + A_s^f R_g^r t_r U_s$$

If there are additional clearing requirements for security, fire protection, etc., then the value R_g^f must also include these and R_g^r would not equal K_g.

The method of analysis to be used will depend on the nature of the problem. Computer programs were used to obtain estimates of earthwork quantities for the expeditionary airfield. This permitted consideration of more cases than would otherwise have been possible.

The procedures used to obtain construction effort estimates are presented in Appendices A through G. The quantities for construction effort determined are production work required and do not include any overhead such as quality control, maintenance, logistics or administration. Total manpower requirement estimates should include adequate allowances for these additional functions.

As will be apparent from a review of Appendices A through G, preparation of the construction effort estimates may take a great deal of time and effort. However, this work can be done in advance of an anticipated operation. If the number of parameters and the number of values assigned to each parameter are not too large, it is possible to compute the construction effort for each and every combination of values. These estimates of construction effort, along with their corresponding parameter values, can be arranged in tables for use in assigning construction effort values to each sub-area. Tables of values generated in the study are contained in Appendices M through S.

Accuracy

The accuracy of any estimate of construction effort depends upon the number of details considered and on the abilities and judgement of the estimator. The rough cost of a building could

be estimated by multiplying the floor area (square feet) by the average cost per square foot for similar buildings recently constructed. A more accurate estimate could be made by considering the cost of purchase and installation for each component within the structure. In either case, the estimator must perform an accurate quantity take-off and judge what appropriate unit prices should be used.

As previously mentioned, the accuracy of estimates for the facilities depends, in part, on the parameters and gradations within each parameter. All other things being equal, the accuracy of an estimate can be improved by increasing the numbers of parameters or gradations.

However, the key in applying the technique is getting good construction estimates for the parameters being considered. Estimates should be done by experienced estimators. All results should be checked, preferably against historical records. All facilities should be estimated in a uniform fashion.

The construction effort values for the Main Supply Route (MSR) were based on data for a double-lane paved road presented in paragraph 3203 of the Engineer Reference Handout (Appendix T, 2).

The construction effort estimates for an Expeditionary Airfield (EAF) were checked against estimates for a support area, medium-lift airfield built under similar conditions using the method presented in Reference 10 of Appendix T. The results agreed closely, except for the cases involving rugged terrain. Since rugged terrain is an extreme case and both estimates predicted

efforts which would preclude sitings in such areas, this discrepancy was not considered significant. The study estimates tended to be more conservative.

No data or alternative techniques were available to check the estimates for the other facilities.

To be useful in preparation of the Engineering Annex the technique should be able to predict overall base construction effort to within $\pm$ 10%. Construction effort estimates prepared for this study attempted to meet this accuracy requirement. These estimates should not be used for an actual operation without examination and confirmation by the appropriate authority.

Terrain Characteristics Pamphlet (TCP)

The information regarding terrain conditions must be made available to the person doing the siting in a form which will permit the siter to assess the desirability of a large number of sites, facilitate the siter's evaluation of the relative merits of various sites, and lead or impel the siter to the selection of the best site. It would be possible to represent the terrain characteristics in the form of actual parameters themselves. This would be similar to the way details are depicted on topographic maps. For instance, on maps, different types of vegetation are shown by different symbols. In a similar fashion, parameter values could be depicted by irregular shapes or symbols. For even a small number of parameters, the resulting clutter would be difficult to analyze.

A square grid system can be utilized with the parameter values represented by suitable colors. The problem of finding a

method for superimposing all parameter value information on each grid would still remain.

Even if a suitable method could be found to represent all parameter class information on a map, the siter would still be required to mentally equate the set of parameter values for each square of the grid to a total construction effort. Since there are several components to the construction effort and each component involves consideration of a different combination of terrain characteristics, this mental exercise would be a very difficult, if not impossible, task.

Instead of the raw parameter information, it is possible to represent, in each square, the total construction effort for a certain type of facility to be built on a site with conditions identical to those in the square. Utilizing this information, the siter can quickly and easily evaluate the desirability of each site. These grids, or Terrain Characteristics Pamphlets (TCP's), take the form of encoded overlays (for a topographic map or set of photographs) which indicate by a color system the construction effort required to locate a certain type of facility on each square of a grid. A sample TCP is shown in Figure 4 following page 54.

Various kinds of TCP's were tested to determine which grid size and color combinations provided the required accuracy with a minimum of work. It was determined through a trial and error procedure that, for accurately predicting the construction effort for an individual facility, within $\pm 10\%$, the dimensions of each square in the grid had to be of at least the same order of

magnitude as the dimensions of the facility. This difficulty was pointed out by trying to site a Main Supply Route (MSR) using a 1000-foot grid system. In certain instances there existed areas such as narrow valleys where a 30-foot-wide road could easily be accommodated with relatively little construction effort. However, the 1,000-foot square grid in such areas would include the steep canyon walls and the roughness parameter would indicate a slope situation of 10 percent or more. Therefore, the grid would appear dark. If a finer grid, say 100' x 100', were used for the MSR TCP, this problem would be generally eliminated and the TCP would clearly indicate the best route. Such a TCP would, however, require 100 times as much work to prepare as a 1000-foot grid TCP. This amount of effort was considered impractical for a manual technique such as the one used in this study.

Using smaller squares also improves the accuracy of the construction effort prediction by providing the estimator with more detailed information of the actual site conditions. If, however, the ±10% accuracy requirement was for the overall MAF-base construction effort, a 250-meter X 250-meter or a 1000-foot x 1000-foot grid would be adequate. The facilities which contribute the most of the overall construction effort, the Expenditionary Airfield (EAF), Ammunition Supply Point (ASP) and the Logistics Support Area (LSA), all have dimensions in the thousand foot area of magnitude. The increased error of the other facilities due to the grid size would not be large enough to upset the overall accuracy.

A 250 meter x 250 meter grid TCP with 5000 squares (about the maximum size which could be manually prepared on short notice) represents about 300 square kilometers of area. If a larger area must be examined, a two step siting process would be necessary. The first stage would involve producing a TCP with a grid size of 500 meters x 500 meters or larger. A 500 meter TCP with 5000 squares would cover 1200 square kilometers. Such a TCP could not be used to determine overall construction effort, but it would point out which areas would have the best construction characteristics relative to each other. After selecting the best general area based on operational as well as construction factors, the normal 250 meter TCP would then be produced. For the reduced accuracy TCP (referred to as a large area TCP because it produced using a large area map), the associated parameters and data would not have to be as refined as for the later TCP used for effort estimation, thereby further reducing the preparation work effort.

For instance, the construction effort of a single major facility, such as an EAF, could be used as being representative of the composite requirements of an entire base. The CE values for the EAF would be used to color code the large area TCP. In this case, the fixed effort for the EAF would not be included since it is the variation in site related construction which are to be emphasized. If the area is so large as to require the use of a large area TCP, then it may be advantageous to include an additional factor in the CE equation to represent the relative difficulty in providing logistic support to sites as their distance from the

landing point increases. If the amount of manpower available for construction is fixed and some of this manpower must be diverted to logistic support at the more remote sites, then this effectively increases the construction effort for all facilities at these sites. As previously mentioned, under these circumstances, this factor would take the form of a multiplier of the basic terms of the CE equation which would increase relative construction effort with distance.

A 5-color TCP was chosen for this demonstration. Light yellow is used to depict squares requiring the least construction effort. Brown is used for squares requiring the most. Yellow, dark yellow and light brown are the intermediate colors. In many instances, the CE values for the worst cases involving less than 25% of the possible parameter combinations would be 10 to 100 times greater than that for the other 75%. If the full range of possible CE values were evenly divided and colors assigned to each part, over 50% of the possible situations would fall into the light yellow category. Since the siter would only be interested in studying the best areas in detail, the color gradation should concentrate on differentiating these areas rather than dealing with the full spectrum. The color assignment therefore finely divides the lower 25% of CE values among the 4 lighter colors and assigns the brown color to the remainder. In actual practice, unless the terrain is extremely uniform in nature, the colors tend to show up in relatively equal proportions. Brown never predominates unless the terrain is extremely rough. The color coding scheme indicating which colors

were assigned to which parameter combinations are presented in Appendices H through L. This coding decision can be made well in advance of any actual operation. All that the people preparing a TCP require is color assignment information in a form similar to that presented in the Appendices referred to above.

A TCP which utilized 24 colors to represent more detailed levels of CE was also examined. Confusion occurred when attempting to determine what the different colors represented. For example, whether dark orange represented more or less work than dark green was not immediately obvious. It was felt that 5 colors gave enough detailed information to enable the siter to select the best sites within the degree of accuracy required.

A previous study (13) recommended utilizing a "checkerboard" TCP with two contrasting basic colors (e.g. green and brown) in various shades arranged in alternating squares. With this system, two distinctly different types of information can be presented simultaneously. As used in the previous study, brown squares represented a general estimate of grading difficulty due to roughness, soil thickness, etc. The green squares represented clearing difficulty. A sample TCP of this type was prepared. The system was judged difficult to use because the color code actually represented raw parameter values which the siter had to mentally convert to construction effort before he could determine the best site for a particular facility. In the recommended system, raw data is converted to a single value construction effort. Therefore, a "checkerboard" TCP is not necessary.

Site parameters affect the construction effort of various types of facilities differently. For instance, an EAF's construction effort is lowest on flat ground. An amphibious Assault Fuel System (AAFS) with its revetments dug into the side of a hill has its lowest CE value in rolling terrain. Therefore, using the same parameter values, the TCP for an EAF in a particular area would look different from a TCP for an AAFS. Therefore, to be able to site and obtain the estimated CE value for each facility directly from a TCP, it would be necessary to have a TCP for each type of facility being considered. This approach was actually done as an early demonstration project in the study. It would be the approach to take if the TCP could be color coded and produced automatically.

In the manual approach, however, so much man-time is involved in actually coloring the TCP that multiple TCP's would be impractical. Therefore, TCP's are prepared for facilities whose CE values are affected similarly by the various parameters. One TCP is for facilities which are best sited on relatively flat terrain without much vegetation cover and with soil material having good bearing capacity. This group includes airfields, Ammunition Supply Points (ASP's) with open revetments, LSA's, cantonments, and MSR's. A second type of TCP is for facilities which prefer sloping terrain and are not affected by vegetation cover or the bearing capacity of the soil. The only facilities this study considered which fell in this category were AAFS's and ASP's with closed revetments. Using these two TCP's, the various facilities within a base could be positioned to take account of the best available space. However,

construction effort would have to be calculated by first determining the parameter values assigned to the squares occupied by the facility, and then looking up the corresponding CE values in a table.

The intent of the TCP is to indicate, in a clear fashion, the most suitable locations for various facilities. A temptation exists to attempt to do too much (i.e. present too much data) on a TCP. Rather than clutter a TCP with data, it was felt that the use of different TCP's in a specified orderly fashion could convey the same information with less risk of confusion.

Facility Template (FT)

A potential base payout is feasible only if the spatial requirements of each type of facility composing the base is met. Compliance with these requirements can be achieved in this methodology through the use of suitable templates which represent the particular spatial requirements of each type of facility.

As with the TCP, a temptation exists to present too much information on a template. Therefore, only pertinent information should be displayed. This information includes:

(a) The physical outline of the boundaries of the facility;

(b) Special restrictions put on areas in the facility's vicinity due to the facility's presence (e.g. safe separation distance, areas where explosives are prohibited, etc.);

(c) Clearance requirements for approach/departure corridors (airfields only);

(d) Likely locations of occupied buildings - (this information needed in conjunctions with b);

(e) A minimum amount of narrative detail to assist in the use of the template.

Templates were made for an Expenditionary Airfield, two types of Ammunition Supply Points, a Logistic Support Area (LSA), and an Amphibious Assault Fuel System. The MSR is drawn in after the other facilities have been placed and does not require the use of a template. The basic block of a cantonment area is a 350' x 350' (110m x 110m) square. This is, in itself, a very small template compared with the other facilities. Moreover, a large number of such templates would be required and can be arranged in a large number of patterns. The CE value for a cantonment area is based on the construction effort required for a 1000' x 1000' square or 250 meter x 250 meter square. Once the other facilities have been located, the cantonments are sited on the lightest colored squares left which still meet the criteria. Spatial requirements are based on standard plans and published navy doctrine (Appendix T - 7, 8, 9, 10). Templates can be prepared in advance of any operational use of the technique.

Priorities

Although each facility is sited separately, each siting must take into account the area that has been pre-empted by previous sitings. Therefore, the sequence in which the individual facilities are sited will determine the total construction effort required. Variation of the sequence in successive iterations is required in order to obtain the optimal siting for all facilities taken together.

The acceptable sequences of siting which can be utilized will depend on operational requiremens and the schedule which

establishes the point in time at which each facility must become operational. The optimal siting becomes the one that provides all facilities at the required point in time while minimizing construction effort. Normally, the airfields are the time-critical facilities in an actual operation and, therefore, should be sited to take advantage of the best possible terrain.

EVALUATION OF SITE PARAMETERS

Practical TCP's could cover fairly large land areas. Moreover, these areas would probably be unavailable for on-site inspections. A prime concern in developing the siting methodology was to assure that the values of the parameters needed to implement the evaluation could be determined.

The most obvious data source is the topographic map. A map is really a different type of TCP in that it attempts to depict specific physical characteristics by various symbols and colors. As the scale of the map grows larger, more room is made available for symbols. Hence, a large scale map usually has a more detailed representation of the terrain.

For the initial large area TCP's, the detail on the standard 1:50,0000 scale military maps with 5-meter contours is sufficient to determine the parameter values. For the more accurate small area TCP, the vegetation and geotechnical details available on 1:24,000 or 1:25,000 scale maps are insufficient for determining the values of those parameters.

Another problem with maps is that they do not always exist on 1:25,000 or even 1:50,000 scale for the more remote areas of the world. In more inhabited regions, maps over 5 years old probably do not depict significant cultural features which could influence siting. The time and man-effort required to produce or update maps over the large areas covered by TCP's would not be compatible with the quick-response nature of the technique itself.

Since modern maps use aerial photographs as a data base, it was considered logical to attempt to use these photographs directly for the TCP's rather than going through the intermediate step of map production. Aerial photography is a common source of military intelligence. The equipment and training required to take, process, and interpret aerial photographs exist. Areas the size of those associated with the TCP's can be photographed and the photographs processed and made available for use in a matter of hours. Therefore, up-to-date data for specific areas can be obtained within the time frame envisioned as appropriate for the siting technique. Different types of photography are available and modern reconnaissance aircraft are equippped to take several different types of photographs simultaneously.

High altitude photography (scale 1:50,000 scale or smaller) is not useful for an inital examination of a large area. Major features such as cities, river systems, and geological structures are best identifed with large area photography. However, small changes in slope are rather difficult to discern unless a magnifying mirror-stereoscope is used. High altitude photography could be used to prepare the large area TCP's, but 1:50,000 scale maps appear more useful.

Low altitude photography (scale 1:25,000 or larger) is required to discern the detail necessary to establish values for the site parameters for the small area TCP. Photographs on a scale of 1:15,000 to 1:20,000 are preferable. Ideally, 1:25,000 scale maps would be used for accurate topographic parameters information

and the photographs would be used for the vegetation and geotechnical information. If the photographs were recent, they could also be used to update the cultural features.

Standard black and white stereoscopic aerial photography generates the most useful general information for the purpose of estimating the site parameters' values. In particular, the area can be topographically mapped, cultural features determined, and broad types of soil and rock identified using this film. The second most useful type of photography is near-visible infra-red color. This film is especially useful for determining particular types of vegetation. Ordinary color photographs supplement the first two types, providing additional information to aid in the identification of vegetation, soil, and rock types. The main use of thermal infra-red photographs would be to identify marsh or wet land which cannot be readily seen with other films. All types should be taken at the same time and on the same scale if possible. Photo missions should be ordered to provide photographs at a scale compatible with the TCP stock and FT's on hand. Ordinarily, it takes longer to custom-make TCP's and FT's to fit the photography than to obtain new photographs.

Earth Resources Technology Satellite (ERTS) imagery generally covers too large an area to be useful for identifying site-specific parameters. ERTS imagery could be helpful to the geotechnical evaluator in suggesting what sort of general geologic structures are present. The evaluator could, in turn, use this information to identify specific details he sees on the aerial photographs.

Another use of ERTS imagery would be to evaluate the seasonal changes in meteorological activity associated with particular regions. Landsat satellites observe the same region on earth once every 18 days. A considerable library of imagery has been accumulated since the first satellite was launched in 1972. Therefore, a region of interest could be checked to determined the seasonality of the weather, possibility of major storms, flood plains, etc.

Side-Looking Airborne Radar (SLAR) imagery (1:50,000-1:100,000 scale) might be useful to the evaluator in identifying geological formations and rock types.

Evaluation of the roughness and vegetation parameter values requires relatively little training or prerequisite experience, as these parameters are visible on the photographs. Geotechnical parameters are less easily determined because, among other reasons, the surface of the material is usually covered by vegetation. As mentioned previously, geotechnical conditions can be correlated with visible surface features to enable an encoder to assign rough values to the geotechnical parameter. If, however, more precise geotechnical parameters are required, inductive reasoning techniques are available for determining this information from aerial photographs (Appendix T, 14). If at all possible, geotechnical data gathered by photograph interpretation should be compared with any field reports or bore logs for previous construction activities in the area.

There are military schools which teach photo interpretation. Although most work in this area is directed towards obtaining intelligence data, there have been, in the past, and may exist today, special teams established to evaluate sites for construction projects. The U.S. Army Corps of Engineers and the National Defense Mapping Agency may have additional information.

For more information regarding the use of remote sensing data for use in site planning, see References Appendix T-1, 4, 5, 6 and 14.

IMPLEMENTATION PROCEDURES

General

The siting technique developed in this study is intended for use during the planning stages of an amphibious operation. The responsibility for implementing the technique would be that of the landing force engineer, a special staff officer.

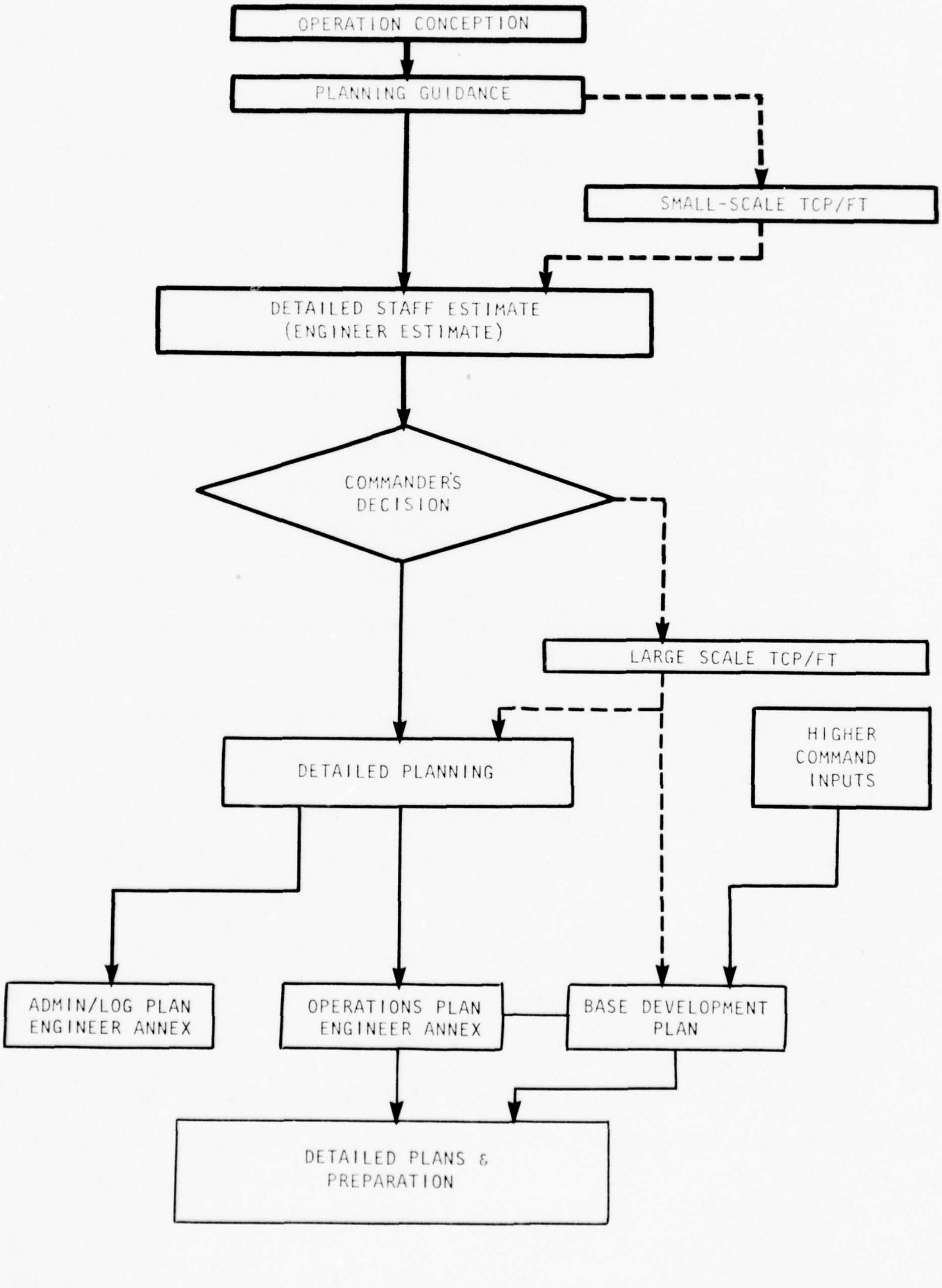
Figure 1 depicts the task order in the planning phase of an operation. As shown, during planning, the siting technique would provide inputs at two stages. During the planning guidance phase, the technique would identify the best general locations for a base throughout the entire AOA and be able to generate gross order-of-magnitude construction effort estimates for bases and major facilities at various locations. These imputs combined with the various other operational factors would serve as the basis for the commander's decision.

The commander's decision would be in the form of an operational scenario including the general location of the base. Based on this information, data-gathering missions would be ordered, if required, and a small area TCP of the final general area produced.

The small area TCP would be used for the detailed planning of the operation and for the base development planning. During the actual siting of the facilities comprising the base, the agency which intends to operate the base (if other than the one conducting the actual amphibious operation) should be invited to

Figure 1

Operations Planning Flow Chart



participate. Certain facilities will have time and/or operational constraints imposed on them by the operational scenario. These facilities should take preference in the siting process to assure that their constraints can be met. The other facilities would then be sited to optimize the base's overall construction effort and, at the same time, meet all the requirements imposed by regulations, doctrine, and the preferences of the various operating agencies.

Once the individual facilities in a base have been sited, construction effort for each can be estimated and a construction and resource allocation schedule developed. Engineering plans and specifications could also be prepared.

The inputs and outputs from a siting exercise are as indicated in Figure 2.

Preparation of TCP and FT KIT

The flow chart for developing TCP's and FT's is indicated in Figure 3. Certain tasks and decisions could be accomplished prior to the actual implementation of the technique. These include the selection of parameters and scales to be used for the TCP's, the calculation of all CE values for all parameter combinations for the various facilities, the assignment of color codes to be used with the various CE values, and the preparation of all base material including the TCP grids and all FT's. The processes involved in accomplishing these tasks are described in the foregoing chapter entitled "Description of the Methodology".

TCP grids should be available for metric scale (1:50,000 and 1:25,000) maps and for English unit scale maps (1:24,000).

Figure 2

INPUTS AND OUTPUTS
FROM
SITING TECHNIQUE

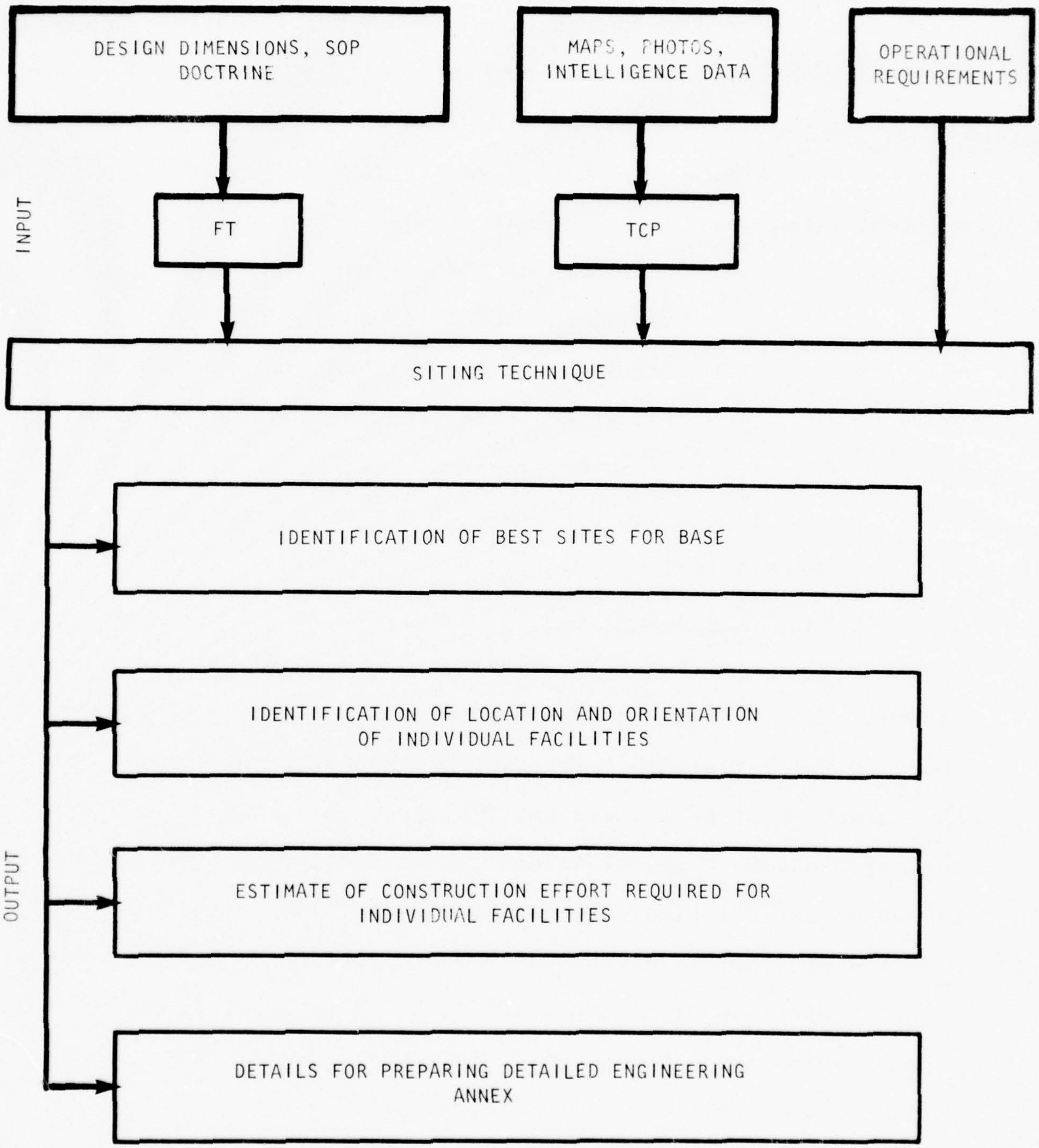
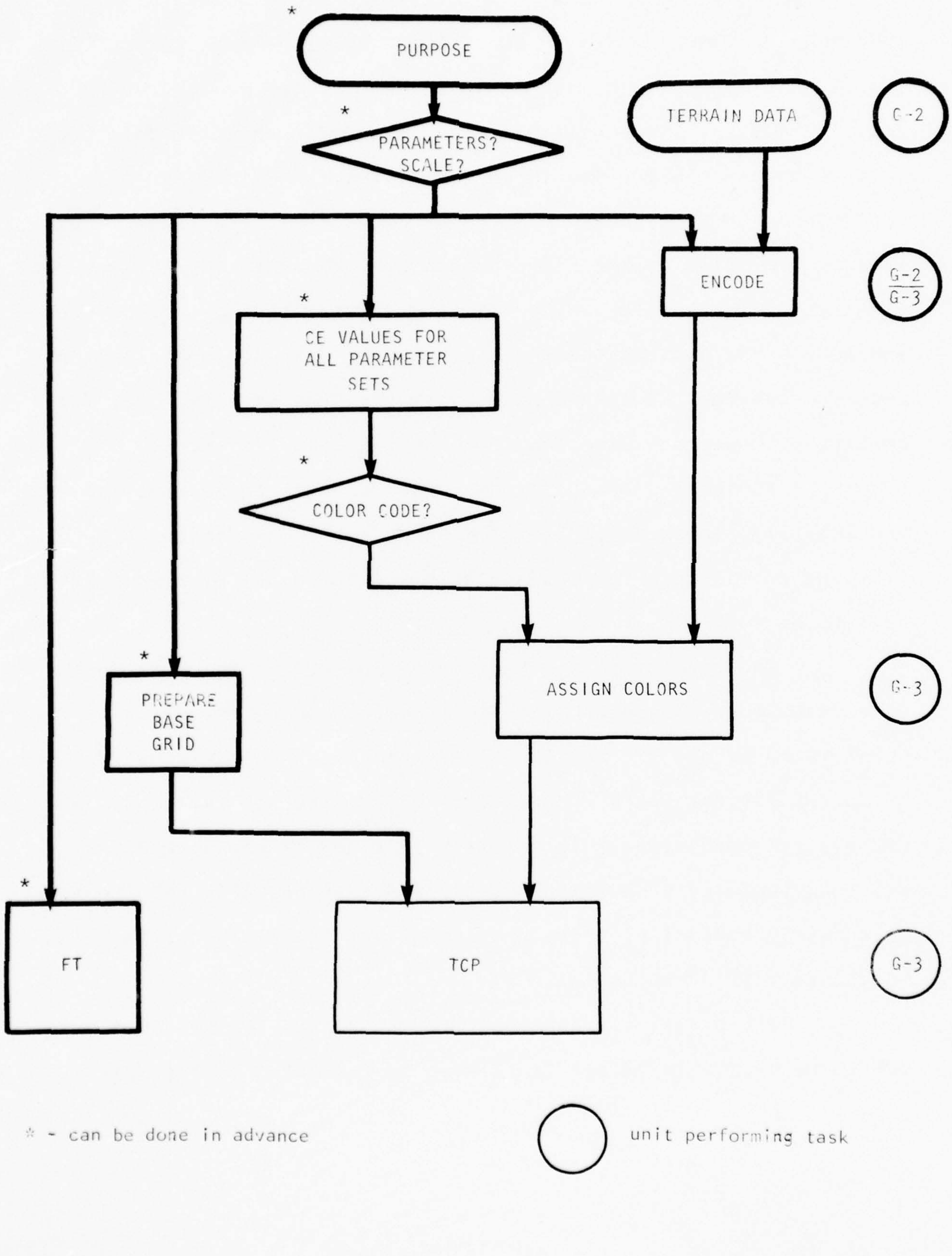


Figure 3

TCP/FT DEVELOPMENT FLOW CHART



Actual grid sizes of 1 cm x 1 cm (metric) and 0.5 inch x 0.5 inch (English) work well for both small area and large area TCP's. FT's for all facilities to be sited should be produced on 1:24,000 and 1:25,000 scales. In actual practice, the difference in scale would only be noticeable for the large facilities (EAF's and ASP's). 1:50,000 scale FT's should also be produced for these larger facilities. TCP grids and FT's are produced by first inking the desired lines onto high quality white drafting film at the appropriate scale and adding the desired information. A silk screen process is then used to transfer the lines and figures to clear acetate. For durability, the acetate base should be at least 4 mils thick.

TCP scales should match those of standard military maps and intelligence photographs. The study's recommendation of 1:50,000 for large area work and 1:25,000 for small area work is felt to be ideal.

The parameters for the large area TCP in the MAF-size base example are presented with their color coding format in Appendices H, I, and J. The CE values were based on the construction of an EAF but the fixed construction effort was not included. An EAF was selected because it was felt that an EAF was normally a critical facility in a siting effort and that an EAF's requirements were fairly typical of a group of important facilities having high CE values (ASP's and LSA's).

The parameters and color coding format for the small area TCP to be used with "flat" facilities is presented in Appendix K.

As for the large area TCP, the computed CE values for an EAF without fixed effort were used to determine color coding.

The parameters and color coding format for the small area TCP to be used with the "hill" facilities is presented in Appendix L. The coding was based on the computed construction effort values for an AAFS.

All the aforementioned decisions, calculations, and materials should be prepared prior to an actual siting exercise in the form of a kit. The items contained with a typical kit would include:

1. A table indicating the color coding for a large area TCP (Appendices H, I, and J)
2. A table indicating the color coding for a small area "flat" TCP (Appendix K)
3. A table indicating the color coding for a small area "hill" TCP (Appendix L)
4. Clear acetate grid overlays in (1 cm x 1 cm) and (0.5 inch x 0.5 inch) sizes
5. Blue-line paper copies of each grid to be used as scratch paper
6. Quantities of Chart-Pak or similar acetate matte color film in the following colors:

Light Yellow	-	CE149
Yellow	-	CF035
Dark Yellow	-	CF038
Light Brown	-	CF127
Brown	-	CF039

   Five sheets of each of the above colors should be sufficient.
7. Several 1:50,000 scale FT's for each large facility such as an EAF or ASP.

8. Several 1:25,000 scale and 1:24,000 scale FT's for each facility normally considered in a siting.

9. Various special writing instruments including a black grease pencil, red, blue and black colored pens for drawing on acetate (Stanford-Sharpie brand) and felt tip markers in shades matching the Chart-Pak colors.

Terrain Data

The initial terrain data required to commence the siting process would be 1:50,000 topographic maps of the general AOA. In lieu of maps, high-altitude black and white aerial photography could be used. In addition, weather information regarding the general direction and magnitude of surface winds within the AOA should also be obtained. This wind information should be available from planners involved in the aviation aspects of the operation. These people will determine generally what runway orientations would be acceptable from a cross-wind component aspect. In general, orientations which cause a runway to have cross wind components greater than 11.5 knots more than 80% of the time are not considered acceptable (Appendix T, 10).

The terrain data required for the small area TCP would be in the form of 1:25,000 or 1:24,000 scale topographic maps augmented by aerial photography (1:25,000 scale or better). If at all possible, additional information regarding the geography, vegetation, climate, agriculture, etc. of the region should be obtained and studied by the encoders to enable them to better interpret features. Construction logs, old trade articles describing construction projects, agriculture soil surveys, etc. would aid in the interpretation of

geotechnical characteristics. Embarked units might consider relying on condensed versions of all available literature transmitted from a rear area support agency rather than attempting to carry aboard all the literature pertaining to all potential areas of interest.

If more than one encoder will be used to prepare a TCP, a thorough briefing and review of reference material should be held prior to encoding. The task leader should present a policy regarding interpreting various codes and should remain available during the encoding process to answer questions and check that his guidelines are being followed.

Uniformity is extremely important to this technique. Non-uniform encoding could cause biased results. If at all possible, only one encoder should be assigned to evaluate each parameter.

The actual construction of a TCP takes place in three steps as shown by the path on the right in Figure 3. The first task is to determine the values of the appropriate parameters for each square. Base maps of the area are spread out on a flat surface to form a mosaic. Blank TCP base grids are laid over the maps to cover the area of interest. Match lines should be drawn onto the base grids to enable the grids and maps to be realigned if they are disturbed. If possible, the TCP grid system should coincide with the military grid system on the maps. The appropriate information should be filled out in the title blocks at this time. These grids are not the base material for the final TCP's. Once they have been filled out, the information will be transferred to other material.

Hence, if grease pencil is used for marking, the grids can be erased and reused.

A mosaic of aerial photographs at an appropriate scale can be used in place of maps. However, only every other photograph should be used in the mosaic (with 60% overlap, there would be no problem). The extras would be held and used with mosaic photos as stereo pairs whenever the encoder needs to check elevation information. Each encoder should have a pocket stereoscope.

The people assigning values to the parameters examine the area under each square individually and mark the appropriate value on the grid itself. A typical marking system is indicated below:

```
                         X = Vegetation
X   Y                    Y = Roughness
  Z                      Z = Geotechnical
```

A typical grid with values assigned and its associated base map are shown in Figures 6 and 7, respectively. The encoders would supplement information from the maps with aerial photography.

Encoding can take a considerable amount of man-effort causing fatigue. To expedite the process, the task can be subdivided. One man or team could be assigned to evaluate each individual parameter. To avoid crowding, the TCP mosaic can be broken down into sections. Each section would be kept on a separate table and encoders would rotate. If distance from the Beach Supply Areas (BSA) is being considered as a parameter, the distance arcs should be made on the base grids before the TCP's are disassembled.

Once a section has been completely encoded, the data and match lines should be hand-copied to a blue-line print of the grid. This process could expedited by running the coded base grid through a blueprint machine if one is available. The base grid can then be erased.

The color assignment is done based on coding instructions on sheets similar to those in Appendices H, I, J, K, and L. After coding is completed, blocks of the same color should be outlined with a felt-tipped pen of a similar color. This outline increases the speed and accuracy of the actual coloring process. See Figure 5 for an example of a grid with color code symbols.

While the print sheets are being encoded, clean base grids can be prepared to serve as the base material for the actual TCP's. Each TCP base should have the appropriate match lines drawn on them and the title blocks filled in. The next step is to position the grids over the maps and trace in all significant cultural features including major highways, railroads, bridges, airports, etc. These match lines and features should be traced using permanent marking pens. It would be preferable, to trace this information on the back of the grid so that it could not be erased or rubbed off accidently. This could be done by tracing off an upside-down map on a light table. It could also be done by tracing the information onto the base grid used to encode parameters, inverting this grid, and then retracing to the TCP base grid.

After the cultural information and match lines have been traced, the color film can be applied. Film should be applied to

the back of the sheet to protect it from wear and scratches. The easiest way is to first lightly mark off the sheets of color film in a grid pattern with the squares the same size as those on the base grid. The person applying the colors can then cut out shapes to match the block on the print sheet. Because the colors are applied to the reverse side of the base grid, the shapes cut out of the film must be mirror images of the shapes on the print sheet. This can cause some confusion at the beginning of the process, but the worker rapidly adjusts. A sample of a completed TCP is presented in Figure 4.

The parameters and color coding scheme used to develop Figures 4, 5 and 6 is based on coding presented in Appendix K.

Completed sheets should be checked by the supervisor to assure that squares have been colored properly. The completed TCP is then ready for use.

Aligning the TCP's and maps, delineating cultural features, and encoding parameter values are tasks requiring reasonably reliable persons with good judgement and an ability to read maps.

The other tasks can be done by less capable people. The learning curve for all tasks is quite rapid. No special training is required for any of the tasks.

<u>Siting Process - Large Area</u>

Upon receipt of planning guidance and after preparation of the suitable TCP's, the landing force officer would examine the AOA to identify the best areas for possible base development. The best sites would be identified by areas of light colors large enough

to accommodate the facilities envisioned. From past experience, the two most difficult types of facilities to site are EAF's and ASP's due to the their size and special off-site requirements. The 1:50,000 scale FT's for these facilities should be oriented on the TCP to check that sufficient area with relative easy construction is available to locate the number of each type of facility envisioned, and also, to check that wind requirements, safe clearance distances, etc., can be met. Very general relative construction effort estimates are possible. In the coding system used for large area TCP's in this study, yellow is associated with the normal average effort expected for base construction. Dark yellow would require 50% more effort than yellow. Light brown would require twice as much effort as yellow. Brown would be 3 times as much effort as yellow. Light yellow would be one half as much effort as yellow. The landing force engineer would add the individual average effort figures for each facility to get an average total effort. From this, he could determine the order of magnitude of construction effort for a base in various locations by multiplying the average effort figure by an appropriate factor.

During this phase of planning, construction effort would be only one of many factors affecting the siting of the proposed base. Other important considerations would include operational, logistic, and political ones. The relative merits of various locations could be discussed at length. The landing force engineer could develope rough estimates to determine construction force size and construction time and eventually, a set of alternative

operational schemes would be developed. From these, based on the landing force commander's decision, a final plan would be developed which would specify the general requirements that the final sitings would have to meet. These would include a list of specific facilities required (directly or indirectly through stating requirements for services such as tons of ammunition per day, which implies that certain facilities be provided), a general base location, a time schedule, and size/make-up of construction forces. This decision automatically initiates the second or large-scale phase of the siting procedure.

The actual siting procedure for the large area TCP is intended to identify general location and orientation of major facilities rather than exact location. After the entire TCP has been laid out and registered over these base maps or photographs, a clear grid is laid on top to coincide with the TCP grid. The siter slides the FT's around on top of the clear grid, looking for good locations. The lighter color square would attract the most attention as possible sites. The nature of the encoding technique means the worst characteristics within a square give the square its darker color. As a square is sub-divided, these characteristics are localized to smaller areas and the rest of the remaining area receives a better construction effort rating. With this in mind, a siter working on a large area TCP need not worry if the fringes of a particular facility intrude into a darker colored area. The effort should be to keep the central part of the facility in light squares.

Once a likely location and orientation have been found, the siter should check that all spatial requirements have been considered. EAR clearance requirements are generally inflexible and must be met. ASP safe distances are not so rigid. If a highway or village lies within their respective safe minimum distances, the highway could be closed or the village depopulated as part of the overall operational scheme. Unless a particularly advantageous siting results, the siter should avoid such a situation. Judgement through experience will serve a siter better than would a rigid set of rules.

The siter should also have a reasonably good idea of the interaction between facilities and the general operational requirements of each type. Such knowledge will serve to reduce the amount of effort required to achieve a siting solution all parties can agree upon. This sort of knowledge is usually acquired through experience. However, a list of basic "do's" and "don't's" for each type of facility could be prepared and issued to inexperienced siters as a sort of guideline checklist to be accomplished.

As an example of this type of consideration, the instrument and visual traffic patterns to an airfield should not conflict with the same patterns of another airfield. Crossing approach and departure corridors create a dangerous operational situation and any siting which caused such a conflict would be questioned.

After a possible siting arrangement for a facility has been achieved, the template can be taped down with clear tape. After all facilities have been sited, an estimator can note the colors under each and work up a rough order-of-magnitude estimate.

Figure 4 Sample Small Area TCP

Figure 5 TCP Grid With Color Codes Assigned

Figure 6 TCP Grid With Parameter Values Assigned

Figure 7 Example of a Typical Base Topography Map

(Note: Figures 4 through 7, which are transparencies and/or in color, are omitted in distributed copies of this report. Copies can be made available by CEL for inspection.)

The clear grid, with the facilities taped to it, would then be removed and another clear grid laid down. The clear grids with facilities applied can then be presented to the land force planning staff for their general comments. The staff may make certain recommendations for modification to the arrangement and these modifications can then be tried on the TCP to check construction effort, spatial requirements, etc.

Even after a final large area arrangement for EAF's and ASP's has been achieved, the arrangement should still be reviewed on the small area TCP. Opportunities to improve the arrangement may be more evident on the more detailed TCP. All trial arrangements should be copied on a blueprint machine, if available, to have a record of each trial and the reasons for its acceptance, rejection or modification.

Actual siting should be done under the direct supervision of an officer or experienced senior NCO. The estimation work could be done under the supervision of junior NCO's.

Siting Process - Small Area

The purpose of the small area siting process is to identify the areas which should be assigned to each facility comprising the base so as to produce a relatively low overall construction effort. At the same time, the process predicts the overall construction effort required.

The technique does not automatically identify the siting solution with the minimal construction effort. A siter can approach

that solution by judicially subjecting various possible solutions to the construction effort prediction process and noting trends.

The technique does not automatically predict the exact final location or outline of a facility. The construction force commander must examine the area assigned to a facility (either from maps or on-site) and then modify the initial standard design to suit the actual topography.

Most of the procedures described for the large area siting process also apply to the small area. The TCP's should be laid out and registered on top of the base maps or photographs. Clear grid sheets should be laid over the TCP's and the grid systems aligned to match.

The commander's decision should be studied to note all requirements placed upon the base and its facilities. Persons familiar with the operational aspects of the various facilities, including a representative of the command who will actually operate the base (if other than the landing force), should be invited to participate. If time is critical, their direct advice would be extremely valuable.

Certain facilities will have critical completion dates. The siter should check the time and man-power available and determine the color of the square with the worst possible parameter values which would still enable the facility to be constructed within the time frame allowed. The tendency to arbitrarily assign the best areas to time-critical facilities should be avoided, Siting such facilities on less advantageous, but still suitable, areas

may enable other facilities to occupy more favorable areas. The net result might mean that the savings in construction effort to non-critical facilities would considerably offset the moderate increase in construction effort to critical facilities. By not automatically assigning the best areas to time-critical facilities, the overall construction effort might be reduced.

The general siting scheme developed during the large area work should be used as a guideline for initial placement trials. General aspects, such as position of the base relative to the operational plan, access to the beach Supply (BSA), use of existing facilities (e.g., road networks), and effects on the local population should have already been considered during that phase. The officer responsible for the small area siting efforts should avoid deviating too much from the large area plan unless certain distinct advantages not previously known become apparent. Any major revision would, of course, have to go through the same approval process as the original large area plan.

The first TCP to be used would be the one for "flat" facilities. Due to their size, magnitude of construction effort, and spatial requirements, the EAF's and open-revetment ASP's should be sited first. The siter should attempt to find the best possible location for each facility with regard to construction effort, existing facilities, etc. within the area assigned by the small-scale plan. After a tentative position has been selected, the template should be taped to the overlay and all spatial requirements checked. Unless it is immediately obvious that not enough room is available,

all ASP requirements should be filled by the open revetment type ASP. During the estimation process later on, it will become evident which ASP requirements could be possibly better handled using the closed revetment type.

After the EAF's and ASP's have been sited, the LSA's should be sited. Care should be taken to assure that the LSA locations do not violate any of the spatial requirements of the previously positioned facilities. The LSA templates are taped to the overlay.

The "flat" TCP should now be replaced by the "hill" TCP. All AFS and Tactical Air Fuel Dispensing Systems (TAFDS), which are identical to AAF facilities for the purposes of this study, should then be sited. Since these facilities have few spatial requirements and prefer to occupy ground less attractive for other facilities, their sitings are relatively easy. These templates should be taped down.

Finally, the "flat" TCP should be reinserted and the cantonment areas selected. The cantonment area size is estimated by the number of grid squares required to house the given number of base personnel. For instance, if 48,000 people must be housed at the base and the grid has 250 m squares, then 37 squares would have to be selected as sites for cantonments (see Appendices G and S). Finally, using the same TCP, the MSR should be drawn on the overlay so that the appropriate facilities are connected by high quality roads.

The order in which facilities are sited does influence the assignment of areas. The above procedure is suggested for use

in the first trial. The siting order should be varied for successive trials to make sure that the solution is not dependent on the order.

A great number of considerations are involved in the location of various facilities relative to each other. For instance, cantonment areas should be located relatively close to work areas so that the men could walk to and from work. All these considerations could be mentioned in the "do's and don't's" checklists for each facility type as stated previously. If people familiar with the various facilities are present during the siting process, these considerations would be mentioned and taken into account as part of the process.

After all facilities have been sited, the overlay is pulled and a copy of the overlay with all facility locations marked is made. This copy is then turned over to estimators who compute the individual efforts required for each facility as positioned on the overlay. The siters can then have the overlay cleaned off and begin siting any alternative schemes which may have become evident during the first trial.

The estimators would begin by copying the parameter code for each square occupied by a facility on the print showing the grid with the facilities positioned. This parameter code information would be obtained from the encoding sheets used to create the TCP. Using construction effort value tables similar to those in Appendices M through S, the estimator would then mark the estimated construction effort value for a particular facility in the appropriate

square. If all of the facility lies within one square or a block of squares with one code, the value in the table is the estimated construction effort for the facility. If the facility lies atop several squares with different codes, the estimator must then use a weighted average placed on the area of the facility within each square to arrive at an estimated effort.

For instance, suppose an LSA was located such that 50% of its area was on squares with the code (2, 1, 1), 25% on squares with code (3, 1, 1), and 25% on squares with code (4, 2, 2). The effort would be calculated as follows:

Code	CE (m-d)	%	% CE (m-d)
2, 1, 1	1428	50	714
3, 1, 1	1574	25	394
4, 2, 2	3304	25	826
		Estimated CE	1934

The construction effort for an MSR can be determined by measuring the length of road to be constructed through each area with the same parameter code and multiplying by the appropriate unit value. Once the estimate is completed, it should be sent to the siters. The individual effort for each facility should be indicated as well as the total.

The estimate will indicate which facilities have efforts near their lowest minimum values and which have efforts which could be substantially improved. In the case of the ASP's, any open, revetment type ASP with efforts exceeding 10,000 man-days might be replaced by a closed revetment type. This estimate should be used as a guideline for refining the siting plan towards a minimum value.

The siting process can be stopped whenever the refinements being made result in changes less than 10% of the overall construction effort for the base.

After a final site plan has been determined, it should be double checked to see that all spatial constraints and mission requirements have been met. The plan should then be transferred to topographic maps and appropriately distributed.

Construction effort estimates for each facility along with comments on the parameters associated with each should be sent to estimators who will use them as a basis for developing schedules and resource requirements.

All material should be packaged and filed separately for possible reuse if changes are required.

MAF - SIZE DEMONSTRATION

The procedures described in the preceding chapter were applied to siting the facilities for a MAF - size base at a remote AOA. Data received to execute this demonstration included a 1:25,000 scale map indicating the AOA and 4 possible landing locations. Nineteen 1:50,000 scale topographic maps of the area near the landing sites were also included.

The numbers and types of facilities to be considered in the demonstration were as follows:

Facility	Number
EAF	3
ASP	4
LSA	2
AAFS (TAFDS)	15

Living quarters for 24,000 personnel also were to be provided.

In preparation of the TCP, only the area within 30 kilometers of the landing points were examined. This area included portions of eight 1:50,000 scale maps. The area covered is depicted in Figure 8 with the landing sites indicated by the four numbered triangles. The 30 kilometer arcs on the right edge of the figure show the extent of territory considered.

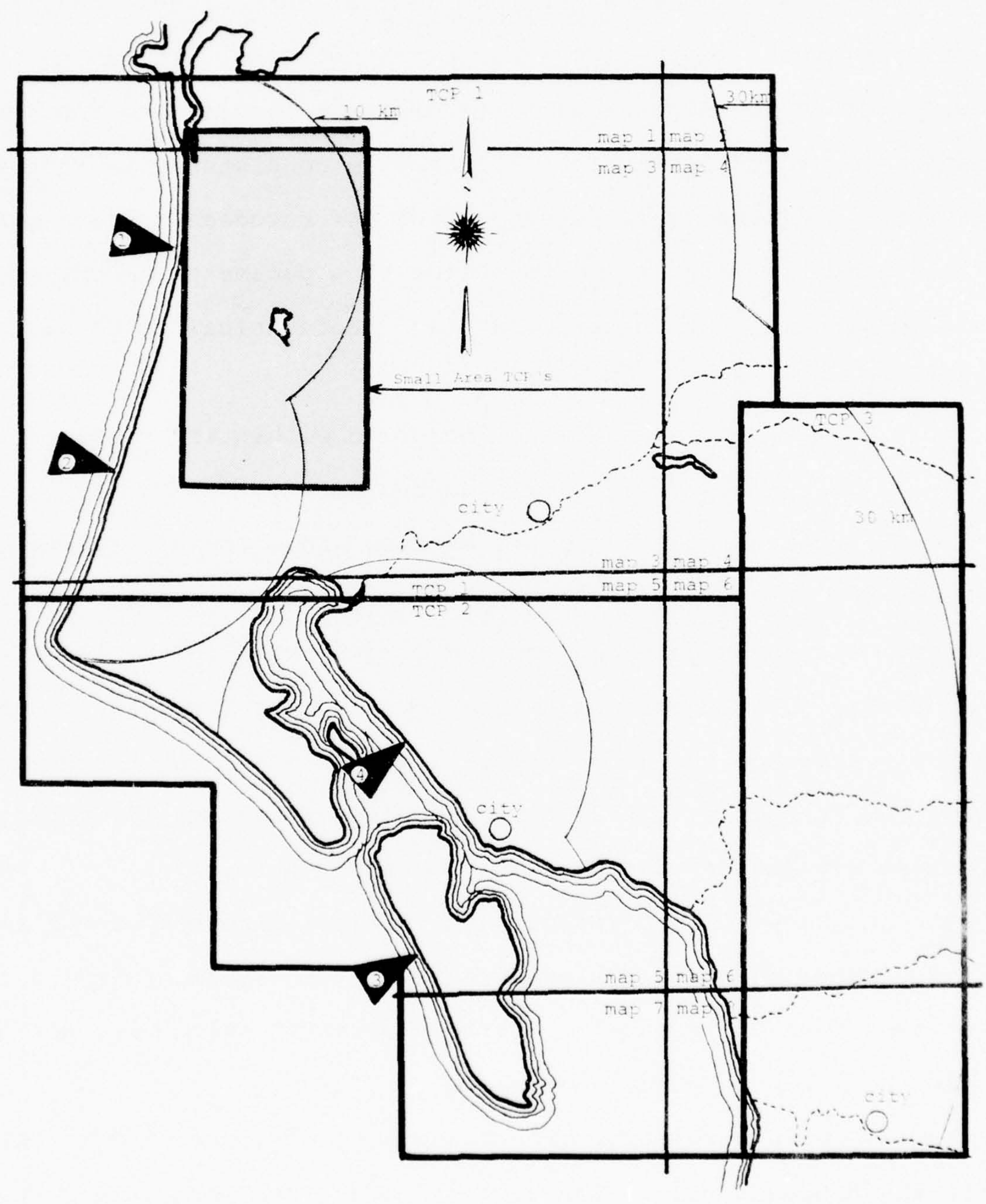
The large area TCP used for this area required 3 grid sheets. The arrangement of these sheets, which are numbered TCP1 through TCP 3, is shown in Figure 8. Approximately 5,000 squares had to be processed. The parameters and color coding scheme used are the ones presented in Appendices H and I. Appendix H was used

for the area within 10 kilometers of the landing points. This area is outlined by the 10 kilometer areas on Figure 8. The color scheme of Appendix I which represents increased CE, was used for the remainder of the area.

Figure 8

Schematic of Land Area Analyzed by TCPs

for the MAF-Size Example



Evaluation of the parameter values had to be based entirely on map information. Since none of the encoders were familiar with the region, questions arose regarding map features. For example, it was not known whether heather more closely resembles grass or brush. Many fields had ditch networks. It was not certain whether the ditches were for drainage (indicating poor base material) or for irrigation. To provide consistency in interpretation, guidelines were developed for the encoders. These guidelines specified what value to assign to a parameter under specific circumstances. For instance, a "bad" geotechnical value was always assigned to a square, whenever:

1. Any marsh symbol occurred within the square
2. Any blue color occurred within the square

Due to a lack of information, the allowable runway orientations due to cross-wind limits were arbitrarily chosen. This information appears as green and red wind circles on the TCP sheets. Any runway orientations with the runway center line bearing in the green portion of the wind circle is acceptable. In this demonstration any runways with true bearings between 010 and 170 degrees or between 190 and 350 degrees would be acceptable.

Based on experience with this small number of TCP's it is estimated that the TCP preparation effort should take 4 man-days for experienced personnel. Metric-square TCP grids were not available, so 1/2-inch grids were used.

Upon completion, the TCP was examined to find likely areas for the proposed base. The best terrain (i.e. largest blocks of

yellow and light yellow squares) was in the southern portion of TCP 3. An area of average terrain existed north of the coastal city on TCP 2. Several medium-size good areas separated by poor areas were located around a large lake on TCP 1. All three areas could accommodate the numbers of EAF's and ASP's required. The clearance requirements for the airfields could be met. Due to the dense population and extensive transportation network, the safe distance requirements for the ASP's posed some problems but solutions could be found.

Due to the lack of specified operational requirements, a large number of options were available. For instance, the siters were not certain whether the base could be spread out (e.g., individual sub-bases consisting of an EAF and ASP, a TAFDS, 3 AAFS's, and a cantonment area located 10 miles apart) or whether the base had to have all its facilities close together for security reasons. In order to proceed with the demonstration, the decision was arbitrarily made to subject a portion of TCP 1 to small area analysis and locate all facilities within that block. Two standard small area TCP's were required to cover the area which is shown by cross hatching in Figure 8.

Since no 1:25,000 scale maps or photographs were available, the parameter data had to be taken off the 1:50,000 scale maps. A 1/4-inch grid was superimposed on the maps and the parameter values recorded on a 1/2-inch grid. The parameters and color coding presented in Appendices K and L were used. Each TCP consisted of 1800 squares. Coding and preparation for experienced personnel took 1.5 man-days per TCP.

For the final siting effort, certain criteria were used which may or may not be valid in actual practice. All airfields had to have their runways parallel to preclude traffic conflicts. Two fields could be located with their runways 1,000 feet apart. The third airfield had to be far enough away (over 3 miles) so that its overhead traffic pattern did not conflict with that of the other airfields. Every EAF would have a TAFDS, 3 AAFS's, and an ASP assigned to it. The TAFDS and ASP would be reasonably close to the airfield. The ASP would be connected to its airfield by a MSR. Each airfield would have a 5,000-man cantonment area located on its parking mat site. ASP's could not conflict with small towns or railroads. An ASP could conflict with a heavy-duty highway if an alternate heavy-duty road existed nearby. The LSA's had to be connected to the BSA and forward areas by MSR quality roads.

Based on the criteria, the facilities were sited as shown in Figure 9. Twelve grid squares were needed to house 24,000 men using the 1/2-inch grid at 1:25,000 scale. 25,400 feet of MSR-quality road had to be constructed.

The estimated construction effort for this siting plan was as follows:

Facility	CE (m-d)
EAF 1	2410
EAF 2	2410
EAF 3	2461
ASP 1	6668
ASP 2	7808
ASP 3	8340
ASP 4	8860
LSA 1	1574
LSA 2	1428

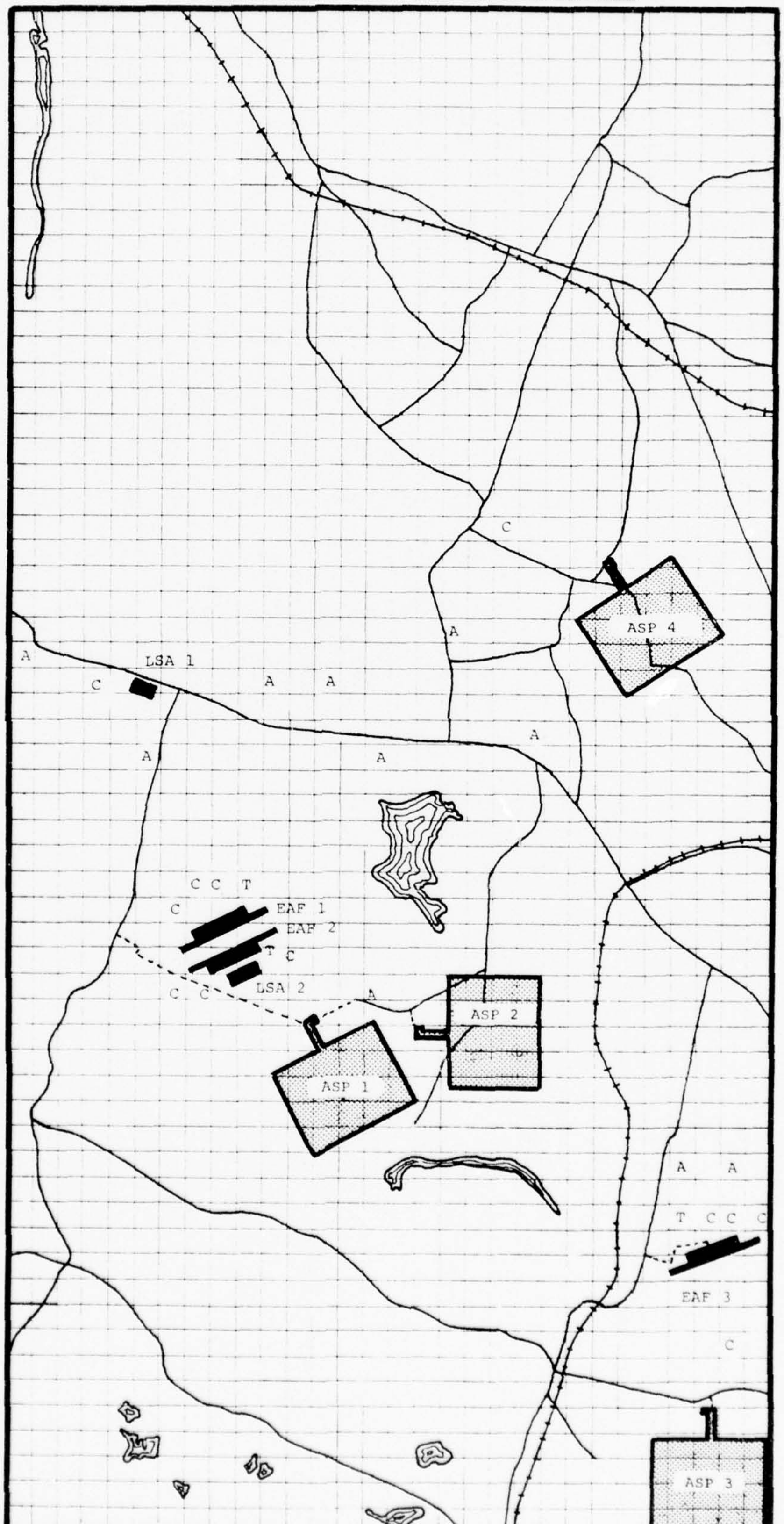
AAFS & TAFDS	4401
MSR (Total)	6172
Cantonment (Total)	541
CE_{total}	53073 m-d

If 3 Naval Mobil Construction Battalions (NMCB's), with 400 production workers in each, work full time on the base (no delays), construction of the base would take 45 days.

Springston (Appendix T, 12) analyzed the same basic situation. The two studies differed in that Springston had the services of a Marine Corps Engineer Battalion. However, 10 more miles of MSR-quality road had to be built. In the Springston study, the construction period was approximately 46 days. Springston's estimates were done by a completely different method.

Figure 9

Completed MAF-Base Siting Plan



— Existing Hwy - - - New MSR A-AAFS T-TAFDS C-Cantonment Area

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The work done in developing the methodology and in preparing the demonstrations supports the following conclusions:

A. A systematic approach to siting facilities in an AOA which is based on establishing parameters for site conditions and characteristics is feasible and can be designed to be within the capability of the military personnel who will be handling the work.

B. A large amount of significant data can be reduced to a single measure, construction effort, that is satisfactory for comparing alternative construction locations for siting purposes.

C. Comparative data on the entire area within the AOA can be presented to the person responsible for selecting sites. The data can be presented in such a manner as to lead the siter to the optimal siting of a group of facilities.

D. The methodology developed can readily be adapted for use with automatic data processing procedures.

E. The siting procedures developed can be expanded to include military operations' considerations.

F. The construction effort estimates used to compare sites can be utilized for preparation of manpower and equipment requirements.

Recommendations

To achieve the full potential of the siting methodology which has been developed, it is recommended that the following actions be taken:

A. Procedures should be developed for the automatic processing of necessary data. When procedures are available the scope and quantity of data used should be extended to take advantage of the increased data processing capability.

B. Concurrent with development of automatic data processing capability, the relationship between construction effort and a wider range of parameters and parameter subdivisions should be undertaken. This will improve the accuracy of the estimates of construction effort.

C. The extent to which construction effort other than that for clearing, earthmoving, and drainage varies with the site conditions should be investigated, and the relationships between construction effort and site condition parameters established.

D. Procedures should be developed and the methodology extended to include military operations' considerations.

APPENDIX A

CALCULATION OF EXPEDITIONARY AIRFIELD (EAF) CONSTRUCTION EFFORT

A model of the EAF was developed to enable construction effort to be predicted as a function of the 3 site parameters.

The EAF dimensions used were those shown in NAVAIR 51-35-7. No other specific geometric requirements, such as maximum allowable grades, etc., were available. The geometric requirements for a medium-lift airfield located in a Corps area and built for C-130 aircraft, as indicated in Table 12-4 of TM 5-333/AFM 86-3, Vol II, were used. This particular field was chosen because it was the same approximate length as the EAF and because C-130 aircraft would probably be expected to operate out of an EAF on refueling and supply missions.

Roughness was defined as the characteristic slope of the terrain on which the airfield was located. The model assumed that the EAF was located on a flat plane which could be tilted transversely with regard to the runway centerline. Cross-section profiles of the airfield surface and the old ground were generated by a computer program and this data was then used by another program to calculate earthwork quantities. The profile program allowed the airfield surface to adjust itself within the limits of the geometric requirements to conform with the old ground profile. The elevation of the airfield relative to the old ground was varied until a balanced cut-fill solution was found. No swell or shrinkage was assumed.

Because of geometric requirements, an airfield could not be located on the side of a plane with a slope of greater than 14.28 percent (7:1). For slopes of greater than 10 percent, it was assumed that the airfield would be located near the top of a ridge so that no clearance problems would be encountered.

Based on this analysis, the following earthwork quantities were chosen to be representative of the earthwork effort associated with the 4 different categories of roughness.

Roughness (g)	Earthwork Quantities (Q_g^{EAF}) (cut or fill)
0-2%	15,000 yards^3
2-10%	150,000
10-30%	1,500,000
30% +	15,000,000

The actual earthwork construction effort (G) is both a function of quantity and of type of material to be moved. For each combination of roughness and geotechnical type, a chart similar to the following was developed:

Roughness ____________________

Geotechnical type ____________________

% of V_c common excavation = M = ____________

% of V_c requiring ripping = P = ____________

% of V_c requiring blasting = B = ____________

% of V_f requiring spoiling = L = ____________

% of V_f used for fill = F = ____________

% of V_f requiring borrowed material = U = ______

where $V_{cut} = V_{fill} = Q_g^{EAF}$

Based on data from the NAVFAC P-504, unit construction effort values U were assigned to each of the material categories as follows:

U common sand and gravel	= 4.0 m-d/1000 y^3
U common clay and organic	= 5.0 m-d/1000 y^3
U rip	= 10.0 m-d/1000 y^3
U blast	= 40.0 m-d/1000 y^3
U spoil	= 4.2 m-d/1000 y^3
U fill (includes compaction)	= 6.0 m-d/1000 y^3
U borrow (includes 1 mile haul)	= 13.0 m-d/1000 y^3

For a particular roughness, and geotechnical type, the construction effort due to earthwork preparation would be:

$$G = \underline{Q_g^{EAF}} \times \left(\frac{M}{100} \times U_m + \frac{P}{100} \times U_p + \frac{B}{100} \times U_b + \frac{L}{100} \times U_l + \frac{F}{100} \times U_r + \frac{U}{100} \times U_u \right)$$

The percentage values assigned to the various material quantities are based on judgement and experience. If an estimator was evaluating quantities for an EAF located on a thick layer of organic material (classified as 'poor'), he may assign a value to L and U greater than 100 percent to indicate that underlying material would have to be replaced (or treated) to improve the bearing capacity. To illustrate, assume that an EAF were to be located on flat terrain with poor geotechnical characteristics.

$$M = 0$$
$$P = 0$$
$$B = 0$$
$$L = 1100\%$$
$$F = 0$$
$$U = 1100\%$$

$$G = \frac{15,000}{1,000}\ (13.0 + 4.2)\ \frac{1,100}{100} = 2,838 \text{ m-d}$$

The reason that 1100 percent was picked is as follows. All of the normal cut and fill would have to be spoiled and borrowed (100%). The airfield's area is approximately 150,000 y^2 (Appendix T-7, 8). If 1 yard of material under the field was removed and replaced by borrow, 150,000 y^3 would have to be spoiled and borrowed. 150,000 y^3 is 10 times the normal 15,000 y^3. Therefore, the amount of material to be cut and borrowed is 10+1 or 11 times the $Q^{EAF}_{(C-2\%)}$.

The representative construction effort due to drainage (D) was based on the sizes of ditches and culverts necessary to handle surface runoff and the thickness of a filter blanket needed to handle subsurface drainage.

For surface drainage, a 1 inch per hour design storm was used. Ditch size was a function of the runoff quantity and velocity. Construction effort depends on the size and length of ditches required and on whether or not riprap protection must be provided.

The thickness of the blanket drain depends on the slope of the terrain and the geotechnical characteristics of the material. The following blanket thickness requirements were established on the basis of general experience.

Blanket Thicknesss
(inches)

Geotechnical/Roughness	0-2%	2-10%	10-30%	30+%
Good-thick	6	3	0	0
Good-thin	6	3	0	0
Bad	12	6	3	3

Blanket material was assumed to be of a select grade which required 16.7 m-d/1000 y^3 to quarry, haul one mile, and place. For example, the D for an EAF to be built on a 2-10 percent slope with good-thick geotechnical characteristcs would be estimated as follows:

Item	Quantity	Unit Cost	Total
Std. ditch w/o riprap	13,840 ft.	X 3.83 m-d/1000'	= 53 m-d
24" diameter steel culvert (CMP)	364 ft.	X 86 m-d/1000'	= 31 m-d
Blanket	14,375 y^3	X 16.7 m-d/1000 y^3	= 240 m-d
TOTAL		D	= 324 m-d

The construction effort due to vegetation cover (C) is a function of vegetation material and of roughness. Roughness is a factor because, with increasing slope, the cut and fill slopes cover larger areas.

The construction effort due to vegetation is in two parts, clearing and stripping.

The following unit work quantities were used based on NAVFAC P-405 guidelines.

Vegetation	Unit effort m-d/1000 y^2
Bare	0.0
Grass	0.5
Brush	1.0
Medium Forest	2.0
Jungle	4.0

Stripping is a function of the amount of material which must be spoiled. To strip and cast, a unit work effort of 4.6 m-d/1000 y^3 was used (Appendix T, 11). Specific references to requirements for stripping were not found. Therefore the following depths of stripping for various types of vegetation were assumed:

Vegetation	Thickness Stripped inches
Bare	0
Grass	6
Brush	12
Medium Forest	18
Jungle	24

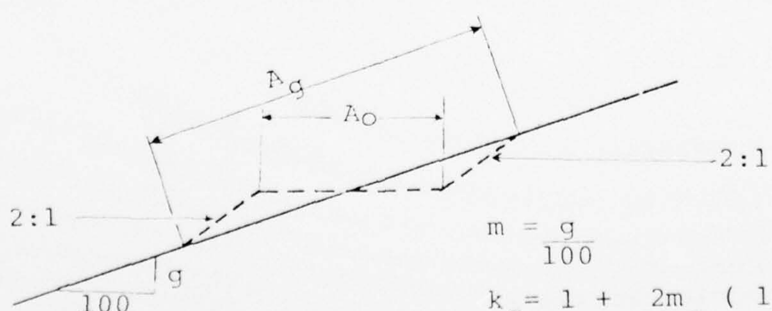
On level ground, the area to be cleared and stripped was 202,140 y^2. The area used for a particular roughness was based on the formula.

$$A_g = k_g \, A_{level}$$

as follows:

Roughness(g)	k_g
0- 2%	1.0
2-10%	1.15
10-30%	1.45
30% +	2.05

The values for k_g were derived by analyzing the following problem:



$$m = \frac{g}{100}$$

$$k_g = 1 + \frac{2m}{1-2m} \left(1 + m^2 \right)^{\frac{1}{2}}$$

As an example, for an EAF constructed in a forest on a 2-10 percent slope, the construction effort to clear the vegetation.

$$A_g = 1.15 \times 202{,}140\ y^2 = 232{,}461\ y^2$$

$$\text{Clearing: } 232{,}461\ y^2 \times \frac{2.0\ \text{m-d}}{1000\ y^2} = 464.9\ \text{m-d}$$

$$\text{Stripping: } \frac{232{,}461\ y^3}{2} \times \frac{4.6\ \text{m-d}}{1000\ y^3} = 534.7\ \text{m-d}$$

$$C = 999.6\ \text{m-d}$$

Use 1000 m-d

The fixed work, required for the EAF was assumed to involve the placement of a special 6 inch thick base course (16.7 m-d/1000 y^3), final grading (3.5 m-d/1000 y^2) and actual placement of the mat planks. (0.5 m-d/1000 $ft.^2$). The base course would only be required if in-situ material was of extremely, low bearing value. The actual area covered by matting would be 136,229 y^2. Therefore, the total work would be 1,470 m-d.

The construction effort for each of the 60 possible combinations of parameter values was computed and tabulated in order to expedite the conversion of the raw grid data to construction effort values for an EAF (see Appendix M).

Ideally, this estimation process should be done by a person familiar with EAF construction. Predicted construction effort values should be checked against historical records to confirm their accuracy. Furthermore, as new equipment and techniques become available, the unit construction efforts may change. Therefore, the estimates should be reviewed and updated periodically.

APPENDIX B

CALCULATION OF AMMUNITION SUPPLY POINT (ASP) - TYPE 1 CONSTRUCTION EFFORT

The model used to evaluate ASP-Type 1 construction effort was based on the conceptual design of an ASP (5,000 st) presented in "Earthwork Construction Support of a Marine Amphibious Force", TN N-1514 -- Technical Note by P. Springston (draft report). In this design, twenty 250 short ton, above ground, non-covered, earth-bermed revetments were laid out in a square grid pattern (4 X 5) on approximate 100-foot center plus a separate revetment used for a work shop. This distance between the outside revetments and the parameter security fence was 400 feet. An area 200 feet outside the fence had to be cleared of vegetation and stripped. The berms were 'U' shaped with 124-foot long sides and 149 feet wide (875 feet between revetments). The berms were 10 feet high with side slopes of 2:1. 21,530 feet of MSR-quality road was required to connect all the revetments in an ASP. A high bearing capacity, well-drained pad had to be provided in each revetment to support the ammunition.

It was assumed that the only areas which would be cleared and stripped would be the road, the revetment areas, and 200 feet on either side of the security fence. Based on this assumption, 1,472,343 y^2 had to be cleared if the ASP was located on level ground. 134,439 y^2 would be stripped. Construction effort for C was computed with the same assumptions and in the same fashion as it was for the EAF.

Each individual revetment would be constructed by cutting into the surface material to prepare a level pad. Excavated material would be used to complete the berm walls. Excess material would be spoiled. The work required to lay and grade a base course and install a pad within a revetment was estimated to be 5.2 man-days.

As an example for an ASP-Type I located on 10-30% slope with good-thin material and covered with brush, the construction effort estimate would be as follows:

C: Clear:

$1,472,343\ y^2 \times 1.45 \times 1\ \text{m-d}/1000\ y^2 =$ 2134.9 m-d

Strip:

$134,439\ y^2 \times \frac{12}{36}\ y \times 1.45 \times 4.6\ \text{m-d}/1000\ y^3 =$ 298.9 m-d

C Total 2433.8 m-d

G: Earthwork per revetment on a 10-30% slope

3	3382 y^3	cut/fill
	5046 y^3	spoil
	1014 y^2	surface to be graded
	50%	common
	50%	rip

$3382\ y^2 \times (0.5 \times 4.0 + 0.5 \times 10 + 6)\ \text{m-d}/1000\ y^3 +$

$5046\ y^3 \times 4.2\ \text{m-d}/1000\ y^3$ = 65.2 m-d

$1014\ y^2 \times 2.2\ \text{m-d}/1000\ y^2$ = 2.2 m-d

67.4 m-d/revet.

$G_{\text{revet.}} \times 21 =$ G total revet = 1415.4 m-d

D: No special drainage facilities required for the revetments = 0 m-d

C_{road}: (G + D + X for road)

21,530 ft. X 0.596 m-d/ft. =12,831.9 m-d

X_{revet}:

5.2 m-d/revet X 21 = 109.2 m-d

$CE_{total} = C_{total} + C_{total\ revet} + C_{road} + X_{total\ revet}$ =16,790 m-d

The calculated construction effort values for all 60 parameter value combinations are listed in Appendix N.

APPENDIX C

CALCULATION OF AMMUNITION SUPPLY POINT (ASP) - TYPE 2 CONSTRUCTION EFFORT

One of the siting problems with the ASP-Type 1 design is that it needs a considerable amount of relatively level ground to keep its construction effort within reasonable bounds.

To illustrate how different designs of a particular facility, each intended to take advantage of a particular type of terrain, could be incorporated into the TCP/FT siting method, the conceptual design for another type of ASP was developed.

The ACP-Type 2 is basically a set of 21 non-standard earth-covered revetments, each assumed to be able to hold 250 st of explosives. Each revetment consisted of a standard Wonder Arch Aircraft Maintenance Shelter covered with at least 10 feet of earth. The front was open (unbarricaded) but wingwalls were provided to present earth from sliding in front of the entrance.

Because the revetments are enclosed, they can be located 100 feet apart (side to side) and 475 feet apart (open front to covered back). (See NAVSEA Op 5, Vol 1 (4th revision) Tables 5-12 and 5-13). However, the additional protections did not allow any reduction in safe separation distance between the ASP and either occupied buildings or public highways (see NAVSEA OP 5...Table 5-19 and 5-8). This compact design means that the length of the road network within the ASP is 6,290 ft. versus 21,530 ft. for the ASP Type 1.

Another difference between the two ASP's is that the ASP-Type 2's construction effort for earthwork is lowest on 10-30 percent

slopes because the arch can be dug into the side of the slope.

The chief disadvantage of the ASP-Type 2 is high fixed construction effort due to the work involved in erecting the arches (6,111 man-days), which causes the construction effort to be high on relatively flat terrain.

In addition to being large, the fixed construction effort is subject to considerable variation because of the construction difficulties which may occur under field conditions as the result of limited availability of the equipment and materials required, such as a crane with a 60-foot boom and portland cement concrete. Unless concrete is being used in considerable quantities on other facilities, the fixed effort should also include work required to obtain aggregate.

Therefore, the ASP-Type 2's usage should only be considered in situations when:

1. Available space is limited; or
2. Only areas with characteristic slopes in excess of 10 percent are available.

The construction effort due to the vegetation is calculated in the same fashion as described for an EAF. The area on level ground which must be cleared is 410,000 y^2.

The construction effort due to earthwork assumes that a notch large enough to accommodate the arch structure would be cut into the side of the slope. Material from the cut would be used to cover the arch once it was erected. Cover would be placed on a 2:1 slope. Borrow material would supplement cut material as cover.

Based on individual cases, the following earthwork estimates for an individual revetment were determined:

Earthwork for Individual ASP-Type 2 Revetment

Roughness (g)	Cut/Fill (y^3/revet)	Borrow (y^3/revet
0- 2%	46	11,629
2-10%	276	9,632
10-30%	922	5,868
30% +	2,074	2,950

Earthwork quantities were converted to man-days by the estimation techniques described for the EAF.

Construction effort due to drainage was based on an estimation process almost identical to that used for the ASP-Type 1.

The fixed construction effort assumed that the steel arch, back wall and side walls, would be standard steel sections and come in a kit form. The sections would be bolted to concrete footers 2 feet wide and 3 feet deep. The total effort to construct a revetment, exclusive of earth cover, would be:

Item	Quantity	Unit Effort	Total
Dig Footers	73 y^3	$\frac{5.4 \text{ m-d}}{1000 \text{ y}^3}$	0.4 m-d
Place concrete	73 y^3	$\frac{.5 \text{ m-d}}{y^3}$	36.5
Erect arches			190.0
Erect back and sides			60.0
Add base course and pave			4.1
		TOTAL	291.0 $\frac{\text{m-d}}{\text{revet}}$

As an example, for an ASP-Type 2 located in heavy jungle

on terrain with roughness greater than 30 percent and good-thick material, the CE estimate would be as follows:

C-clearing $410{,}000\ y^2 \times \frac{4\ \text{m-d}}{1000\ y^2} \times 2.05 = 3362.0$ m-d

C-stripping $410{,}000\ y^2 \times \frac{2\ Y}{3} \times \frac{4.6\ \text{m-d}}{1000\ y^3} \times 2.05 = \underline{2577.5}$ m-d

C Total = 5939.5 m-d

G-individual revetment:
Assume 70% of the cut is common
30% of the cut is rip

G-individual revetment =

$$\frac{2{,}074\ y^3}{\text{revet.}}\ \frac{(0.7 \times 4.0 + 0.3 \times 10.0 + 1.0 \times 6.0)}{1000}\ \frac{\text{m-d}}{y^3} + \frac{2950\ y^3}{\text{revet.}}$$

$\times \frac{13.0\ \text{m-d}}{1000\ y^3}$ = 62.8 m-d/revet

G 21 revetment total = 1319 m-d

D-individual revetments
none required 0 m-d

CE roads (includes G, D and X for roads)

6290 Ft. X 1.057 m-d/ft. = 6648.5 m-d

X-fixed revetment $\underline{6111.0}$ m-d

CE Total = 20,018.0 m-d

The calculated construction effort values for all 60 parameter value combinations are listed in Appendix O.

APPENDIX D

CALCULATION OF LOGISTIC SUPPORT AREA (LSA) CONSTRUCTION EFFORT

The LSA model used to compute construction effort was based on the conceptual design in "Earthwork Construction in Support of a Marine Amphibious Force--A Case Study", TN N-1574 Technical Note by P. Springston.

Straddle cranes and other specialized material handling equipment used in container yards generally require level surfaces with well supported road surfaces over which to operate. These requirements are dictated by the awkward design of the equipment and the high-point loadings imposed by the tires on the surface. Therefore, the LSA model assumed that all roadways, operating surfaces and storage pads had to be level and had to consist of an aluminum matting surface on a high quality, well drained base and subgrade.

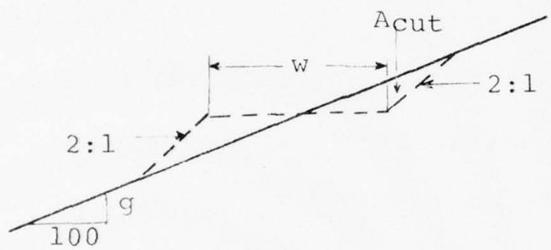
For LSA's located on sloped terrain, (i.e., roughness 2-10 percent or more) it was assumed that the LSA could be divided into 4 separate sections, each on its own terraced level.

Developing a conceptual design for the drainage of this terraced arrangement proved to be a challenge. Thick filter drain blankets were used under each pad. Interceptor drains were located on the uphill side and downhill side of each pad. All ditches were connected by culverts. The principal concern was to keep the run-off in protected channels to prevent erosion and possible slope failure due to saturation.

The total areas required to be cleared and stripped were computed to be as follows:

Roughness	Area y^2
0- 2%	91,000
2-10%	132,038
10-30%	166,482
30% +	235,373

Grading quantities (cut/fill) were calculated as follows:



$$m = \frac{g}{100}$$

$$A_{cut} = \frac{mw^2}{8(1-2m)}$$

For the case where the slope was 0-2%, was assumed equal to 650 feet and m = 0.01. The area was multiplied by 1260 feet and the resultant volume converted to cubic yards.

For the other three roughness cases, the LSA was assumed to be constructed in 4 steps. Each step was 312 ft. wide and 828 ft. long.

Grading quantities were as follows:

Earthwork Quantities Per LSA y^3

Roughness	(m)	Cut/Fill
0- 2%	0.01	25,149
2-10%	0.06	101,769
10-30%	0.20	497,536
30% +	0.45	6,716,736

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Based on these quantities, grading construction effort was calculated in the standard fashion.

Fixed construction effort involved placing a base course and installing matting.

The fixed effort for the 0-2% case is 980 man-days. For the other 3 cases, the effort is 1240 man-days.

As an example, for a LSA located in a forest, on a 2-10% slope with good-thick material, the construction effort was estimated as follows:

C: $132{,}038\ y^2 \times 2\ \text{m-d}/1000\ y^2 = 264.1$ m-d

$132{,}038\ y^2 \times \frac{18}{36}\ y \times 4.6\ \text{m-d}/100\ y^3 = \underline{303.7}$ m-d

CE Total = 567.8 m-d

G: Assume all cut/fill
90% common
10% rip
$101{,}769\ y^3 \times (.9 \times 4 + .1 \times 10 + 6)\ \text{m-d}/1000\ y^3 =$

1078.8 m-d

D: Filter Blanket

$132{,}038\ y^2 \times \frac{3}{36}\ y \times 16.7\ \text{m-d}/1000\ y^3 = 183.8$ m-d

Ditches

6800' X 3.0 m-d/1000' = 20.4 m-d

Pipe

1464' X 83 m-d/1000' = $\underline{121.5}$ m-d

D Total = 325.7 m-d

X: X Total = $\underline{1240.0}$ m-d

CE Total 3212.3 m-d

The construction effort values for all 60 parameter values are presented in Appendix P.

APPENDIX E

CALCULATION OF AMPHIBIOUS ASSAULT FUEL SYSTEM (AAFS) CONSTRUCTION EFFORT

The conceptual design of a model AAFS was hampered by a lack of information as to the exact purpose of the berms around the fuel bladders. A 20,000 gallon fuel bladder's dimensions are 23 ft. by 25 ft. by 5-3/4 ft. 20,000 gallons of JP5 Occupies approximately 2,700 ft^3. Therefore, if the sole purpose of the berms is to contain the spill from a ruptured bladder with some safety factor (say 50 percent), then the height of the berm walls would be dictated by the volumetric requirements of the bladder.

Another purpose of the berm walls might be to protect the bladder from low angle fragments or from heat due to a fire in an adjacent cell. In this case, the berm walls would have to be at least as high as the full bladder (5-3/4 ft.).

For this study, it was decided to use only the volumetric requirement.

Berms were designed to be 45 ft. by 45 ft. at the top and 4-1/2 ft. high. Berm walls were 3 ft. wide at the top and the sides constructed on a 2:1 slope. The enclosed volume of such a structure is 5852 ft.^{3} which gives a safety factor of over 2.

The configuration of individual berms in a tank farm was based on the conceptual design in "Earthwork Construction in Support of a Marine Amphibious Force-A Case Study", TN N-1514 Technical Note by P. Springston. In this configuration, 6 berms are evenly located in a circle so that their outer corners are 120 ft. from the center.

The AAFS itself consists of 5 tank farms. Using the conceptual design in SP 326/204 once again, the tank farms are located within a 1,000 ft. square with one at the center and one at each corner.

Like an ASP-Type 2 revetment, an AAFS berm can be cut into the side of a hill and is, therefore, relatively unaffected by the roughness of the terrain. A computer technique similar to the one used for the EAF earthwork analysis was used to estimate earthwork quantities. The following were the earthwork quantities per cell used for the various roughness parameters:

Roughness (g)	Earthwork per cell (y^3)	Surface Area per cell (y^2)
0- 2%	354 all borrow	460
2-10%	236 cut/fill	395
20-30%	307 cut/fill	330
30% +	590 cut/fill	265

Earthwork quantities were converted to construction effort using the techniques described for the EAF. For instance, for an AAFS located on a 2-10 percent slope with good thick soil:

$$G = \frac{236\ y^3}{\text{cell}} \text{ X } 36 \text{ cells } \frac{(0.75 \text{ X } 4 + 0.25 \text{ X } 10 + 1.0 \text{ X } 6)}{1000} \frac{\text{m-d}}{y^3}$$

$$+ 36 \text{ X } 395\ y^2 \text{ X } 2.2 \text{ m-d}/1000\ y^2 = 129 \text{ m-d}$$

No drainage or fixed effort would be required.

It was assumed that the entire AAFS area including a 200 ft. strip along the outside of the perimeter had to be cleared (217,778 y^2). Only the tank farm areas had to be stripped (25,120 y^2). Estimation techniques for determining C are as described for the EAF. If the AAFS whose G value was previsouly calculated were located on grass:

$$C = 217{,}778\ y^2 \times 1.15\ (k_g \text{factor}) \times \frac{0.5\ \text{m-d}}{1000\ y^2} + 25{,}120\ y^2 \times$$

$$\times \frac{1}{6}\ y \times 1.15 \times \frac{4.6\ \text{m-d}}{1000\ y^3}$$

$$C = 147\ \text{m-d}$$

Therefore, the total CE for the above facility would be:

$$CE = 276\ \text{m-d}$$

JP, AVGAS and MOGAS are Hazard Group I explosives (NAVSEA OP5 Volume 1 Fourth Revision, Table 5-22). Therefore, the edge of the AAFS must be located at least 100 ft. away from any occupied building, public highway, etc. (NAVSEA OP5...Table 5-1).

Some consideration must be given to avoiding the location of fuel cells on slopes immediately above occupied buildings. A ruptured wall and bladder could possibly cause burning fuel to engulf the structures.

The cell and tank farm configurations used were solely for estimation purposes. After the best sites have been identified, the component items should be sited to take best advantage of the terrain.

The construction effort values for all 60 parameter combinations are presented in Appendix Q.

APPENDIX F

CALCULATION OF MAIN SUPPLY ROUTE (MSR) EFFORT

The construction effort estimates for roads were based on data from paragraph 3203 of the Engineer Reference Handout Academic Year 1975-1976 prepared by MCDEC. The data presented the work effort for different types of roads under various site conditions on a man-hours per kilometer basis. These data were converted into a man-day per ft. basis by dividing by 3168 ft. per kilometer and 8 man-hours per man-day.

Six terrain conditions in the reference were assumed to correspond directly to six different parameter sites. For instance, the "flat prairie-average vegetation - 0-20% rock" description was assumed to be equivalent to the "brush-flat-good thick" parameter set. Values for construction effort for at least one set within all four roughness categories were obtained directly.

To obtain values for the other 54 parameter sets, the fixed construction effort and clearing effort were computed. Clearing effort was based on clearing and stripping a 56 ft. strip for a 2 lane MSR. The assumptions and unit work effort described earlier were utilized. Fixed effort was based on paving a 23 ft. wide surface and was estimated to be 0.140 m-d/ft.

The appropriate clearing efforts and the fixed effort were then subtracted from the 6 known overall efforts to determine the basic grading and drainage efforts. To find the other 6 basic grading and drainage efforts, the assumption was made that the grading and

drainage efforts for roads having the same roughness values but different geotechnical characteristics would have the same ratio as those for an EAF under similar conditions.

Once all 12 basic grading and drainage efforts have been determined, the fixed efforts and various clearing efforts can be added to determine all 54 other values.

For instance, to find the construction effort for a road located on a 30+% slope, jungle, and bad material, the following procedure would be used:

Given: 30+%, Forest, Good Thick		
28,170 m-h/km =		1.112 m-d/ft.
Less:		
Clearing Effort: 30+% Forest		0.055 m-d/ft.
Fixed Effort:		0.140 m-d/ft.
Basic G+D Effort - 30 +%		0.917 m-d/ft.

Ratio of G & D Effort for EAF's

$$\frac{\text{30+\% Bad}}{\text{30+\% Good thick}} = \frac{\text{169,358 m-d}}{\text{168,178 m-d}} = 1.007$$

G &D Effort for Road: 30+%		
0.917 m-d/ft X 1.007	=	0.923 m-d/ft.
Clearing Effort: 30+% Jungle	=	0.090 m-d/ft.
Fixed Effort	=	0.140 m-d/ft.
Total Construction Effort Jungle 30+% Bad		1.153 m-d/ft.

The computed construction effort values of a standard 2-lane MSR for all 60 parameter value combinations are presented in Appendix R.

These values are utilized for the estimation of construction effort values for ASP's which contain roads similar to a MSR. The construction effort values for a single lane light duty road used in cantonment areas were calculated in a similar fashion.

APPENDIX G

CALCULATION OF CANTONMENT CONSTRUCTION EFFORT

The cantonment model is based on blocks of Southeast Asia Berthing Huts. Each block contains 24 huts arranged in a rectangular grid pattern 6 side by side and 4 end to end. Each hut can accommodate 10 men. Spaces for a shower, 2 latrines and a small recreation area are also provided. Each block would be surrounded by a light duty single lane road. The dimensions of a block from road centerline to road centerline is 350 ft. X 350 ft. 8.2 blocks can be accommodated in a 1000 ft. square. 5.5 blocks can be accommodated in a 250 meter square. (Appendix T, 12).

Vegetation clearing effort, C, includes the clearing and stripping of only the road areas and five 40 ft. wide lanes through each block. Road clearing is taken into account as part of the unit road construction effort. The 40 ft. wide lanes in each block account for 6889 y^2 at area which must be cleared.

Because the huts are on stilts, they can be located on uneven ground of up to a 10 percent grade. Therefore, for all terrain with roughness less than 10 percent, no earthwork effort is required for the berthing areas unless organic material is present. If organic material were present in such areas, it was removed to a depth of 2 ft. and replaced by borrow for health reasons.

For slopes over 10%, the 40 ft. strips would be cleared transverse to the slope and the slope graded to 10%. The resultant earthwork is as follows:

Roughness	Cut Quantity per Strip (y^3)
10-30%	72
30% +	1723

Earthwork quantities were converted to construction effort using the same procedures described for an EAF.

No drainage facilities other than culverts were provided within a block. Culverts were located under the roads, which would probably be higher than the cantonment areas and might act as dikes.

For a block located in a forest on flat terrain with bad material, the calculated work effort would be as follows:

C: block interior only

$$6889\ y^2 \times 2.0\ \text{m-d}/1000\ y^2 = 13.8\ \text{m-d}$$
$$6889\ y^2 \times \frac{18}{36}\ y \times 4.6\ \text{m-d}/1000\ y^3 = \underline{15.8}\ \text{m-d}$$
$$\text{C Total} = 29.6\ \text{m-d}$$

G: replace 2 ft. of material

$$6889\ y^2 \times \frac{2}{3}\ y \times 17.2\ \text{m-d}/1000\ y^3 = 79.0\ \text{m-d}$$

D: 80 ft. CMP X 86 m-d/1000 ft. = 6.9 m-d

CE road 350 ft. X 0.0825 m-d/ft. = $\underline{28.9}$ m-d

144.4 m-d

The calculated construction effort values for all 60 parameter value combinations are presented in Appendix S.

APPENDIX H

COLOR CODES FOR A LARGE AREA TCP (0-10 KM)

Codes:

X = Vegetation
1 - Bare
2 - Brush
3 - Forest

Y = Roughness
1 - Flat
2 - Hilly
3 - Rough

Z = Geotechnical
1 - Good Thick
2 - Good Thin
3 - Bad

LY - Light Yellow
Y - Yellow
DY - Dark Yellow

LB - Light Brown
B - Brown

Code X	Code Y	Code Z	Color Code	Code X	Code Y	Code Z	Color Code	Code X	Code Y	Code Z	Color Code
1	1	1	LY	2	1	1	LY	3	1	1	Y
1	1	2	LY	2	1	2	LY	3	1	2	Y
1	1	3	LB	2	1	3	LB	3	1	3	LB
1	2	1	Y	2	2	1	Y	3	2	1	DY
1	2	2	Y	2	2	2	DY	3	2	2	DY
1	2	3	DY	2	2	3	LB	3	2	3	LB
1	3	1	B	2	3	1	B	3	3	1	B
1	3	2	B	2	3	2	B	3	3	2	B
1	3	3	B	2	3	3	B	3	3	3	B

APPENDIX I

COLOR CODES FOR A LARGE AREA TCP (10-30 KM)

Codes:

X = Vegetation
1 - Bare
2 - Brush
3 - Forest

Y = Roughness
1 - Flat
2 - Hilly
3 - Rough

Z = Geotechnical
1 - Good Thick
2 - Good Thin
3 - Bad

LY - Light Yellow
Y - Yellow
DY - Dark Yellow

LB - Light Brown
B - Brown

Code X	Code Y	Code Z	Color Code	Code X	Code Y	Code Z	Color Code	Code X	Code Y	Code Z	Color Code
1	1	1	LY	2	1	1	LY	3	1	1	Y
1	1	2	LY	2	1	2	LY	3	1	2	Y
1	1	3	LB	2	1	3	LB	3	1	3	LB
1	2	1	Y	2	2	1	DY	3	2	1	DY
1	2	2	Y	2	2	2	DY	3	2	2	DY
1	2	3	DY	2	2	3	LB	3	2	3	LB
1	3	1	B	2	3	1	B	3	3	1	B
1	3	2	B	2	3	2	B	3	3	2	B
1	3	3	B	2	3	3	B	3	3	3	B

APPENDIX J

COLOR CODES FOR A LARGE AREA TCP (30-60 KM)

Codes:

X = Vegetation	Y = Roughness	Z = Geotechnical
1 - Bare	1 - Flat	1 - Good Thick
2 - Brush	2 - Hilly	2 - Good Thin
3 - Forest	3 - Rough	3 - Bad

LY - Light Yellow
Y - Yellow
DY - Dark Yellow

LB - Light Brown
B - Brown

Code X	Code Y	Code Z	Color Code	Code X	Code Y	Code Z	Color Code	Code X	Code Y	Code Z	Color Code
1	1	1	LY	2	1	1	LY	3	1	1	Y
1	1	2	LY	2	1	2	LY	3	1	2	Y
1	1	3	LB	2	1	3	LB	3	1	3	LB
1	2	1	Y	2	2	1	DY	3	2	1	DY
1	2	2	Y	2	2	2	DY	3	2	2	LB
1	2	3	LB	2	2	3	LB	3	2	3	LB
1	3	1	B	2	3	1	B	3	3	1	B
1	3	2	B	2	3	2	B	3	3	2	B
1	3	3	B	2	3	3	B	3	3	3	B

APPENDIX K

COLOR CODES FOR A SMALL AREA TCP (FLAT FACILITIES)

Codes:

X = Vegetation
- 1 - Bare
- 2 - Grass
- 3 - Brush
- 4 - Forest
- 5 - Jungle

Y = Roughness
- 1 - Flat
- 2 - Rolling
- 3 - Hilly
- 4 - Cliffs

Z = Geotechnical
- 1 - Good Thick
- 2 - Good Thin
- 3 - Bad

LY - Light Yellow
Y - Yellow
DY - Dark Yellow

LB - Light Brown
B - Brown

Code			Color Code	Code			Color Code	Code			Color Code
X	Y	Z		X	Y	Z		X	Y	Z	
1	1	1	LY	3	1	1	LY	5	1	1	Y
1	1	2	LY	3	1	2	LY	5	1	2	Y
1	1	3	LB	3	1	3	LB	5	1	3	LB
1	2	1	Y	3	2	1	DY	5	2	1	LB
1	2	2	Y	3	2	2	DY	5	2	2	LB
1	2	3	DY	3	2	3	DY	5	2	3	LB
1	3	1	B	3	3	1	B	5	3	1	B
1	3	2	B	3	3	2	B	5	3	2	B
1	3	3	B	3	3	3	B	5	3	3	B
1	4	1	B	3	4	1	B	5	4	1	B
1	4	2	B	3	4	2	B	5	4	2	B
1	4	3	B	3	4	3	B	5	4	3	B
2	1	1	LY	4	1	1	Y				
2	1	2	LY	4	1	2	Y				
2	1	3	LB	4	1	3	LB				
2	2	1	Y	4	2	1	DY				
2	2	2	Y	4	2	2	DY				
2	2	3	DY	4	2	3	LB				
2	3	1	B	4	3	1	B				
2	3	2	B	4	3	2	B				
2	3	3	B	4	3	3	B				
2	4	1	B	4	4	1	B				
2	4	2	B	4	4	2	B				
2	4	3	B	4	4	3	B				

APPENDIX L

COLOR CODES FOR A SMALL AREA TCP (HILL FACILITIES)

Codes:

X = Vegetation
1 - Bare
2 - Grass
3 - Brush
4 - Forest
5 - Jungle

Y = Roughness
1 - Flat
2 - Rolling
3 - Hilly
4 - Cliffs

Z = Geotechnical
1 - Good Thick
2 - Good Thin
3 - Bad

LY - Light Yellow
Y - Yellow
DY - Dark Yellow

LB - Light Brown
B - Brown

Code X	Code Y	Code Z	Color Code	Code X	Code Y	Code Z	Color Code	Code X	Code Y	Code Z	Color Code
1	1	1	Y	3	1	1	DY	5	1	1	B
1	1	2	Y	3	1	2	DY	5	1	2	B
1	1	3	Y	3	1	3	DY	5	1	3	B
1	2	1	LY	3	2	1	DY	5	2	1	B
1	2	2	LY	3	2	2	DY	5	2	2	B
1	2	3	LY	3	2	3	DY	5	2	3	B
1	3	1	LY	3	3	1	DY	5	3	1	B
1	3	2	LY	3	3	2	DY	5	3	2	B
1	3	3	LY	3	3	3	DY	5	3	3	B
1	4	1	Y	3	4	1	LB	5	4	1	B
1	4	2	Y	3	4	2	LB	5	4	2	B
1	4	3	Y	3	4	3	LB	5	4	3	B
2	1	1	DY	4	1	1	LB				
2	1	2	DY	4	1	2	LB				
2	1	3	DY	4	1	3	LB				
2	2	1	Y	4	2	1	LB				
2	2	2	Y	4	2	2	LB				
2	2	3	Y	4	2	3	LB				
2	3	1	Y	4	3	1	LB				
2	3	2	Y	4	3	2	LB				
2	3	3	Y	4	3	3	LB				
2	4	1	DY	4	4	1	B				
2	4	2	DY	4	4	2	B				
2	4	3	DY	4	4	3	B				

APPENDIX M

CONSTRUCTION EFFORT VALUES FOR AN EAF

Code:

X = Vegetation
1 - Bare
2 - Grass
3 - Brush
4 - Forest
5 - Jungle

Y = Roughness
1 - Flat
2 - Rolling
3 - Hilly
4 - Cliffs

Z = Geotechnical
1 - Good Thick
2 - Good Thin
3 - Bad

Code X	Code Y	Code Z	CE Values (Man-days)	Code X	Code Y	Code Z	CE Values (Man-days)	Code X	Code Y	Code Z	CE Values (Man-days)
1	1	1	2154.	3	1	1	2666.	5	1	1	3583.
1	1	2	2159.	3	1	2	2671.	5	1	2	3588.
1	1	3	5255.	3	1	3	5767.	5	1	3	6684.
1	2	1	3373.	3	2	1	3962.	5	2	1	5016.
1	2	2	3474.	3	2	2	4063.	5	2	2	5117.
1	2	3	3978.	3	2	3	4567.	5	2	3	5621.
1	3	1	17998.	3	3	1	18740.	5	3	1	20070.
1	3	2	19356.	3	3	2	20098.	5	3	2	21428.
1	3	3	19178.	3	3	3	19920.	5	3	3	21250.
1	4	1	169648.	3	4	1	170698.	5	4	1	172577.
1	4	2	187656.	3	4	2	188706.	5	4	2	190585.
1	4	3	170828.	3	4	3	171878.	5	4	3	173757.
2	1	1	2410.	4	1	1	3023.				
2	1	2	2415.	4	1	2	3028.				
2	1	3	5511.	4	1	3	6124.				
2	2	1	3667.	4	2	1	4372.				
2	2	2	3768.	4	2	2	4473.				
2	2	3	4272.	4	2	3	4977.				
2	3	1	18369.	4	3	1	19258.				
2	3	2	19727.	4	3	2	20616.				
2	3	3	19549.	4	3	3	20438.				
2	4	1	170173.	4	4	1	171429.				
2	4	2	188181.	4	4	2	189437.				
2	4	3	171353.	4	4	3	172609.				

APPENDIX N

CONSTRUCTION EFFORT VALUES FOR AN ASP-TYPE 1

Code:

X = Vegetation
1 - Bare
2 - Grass
3 - Brush
4 - Forest
5 - Jungle

Y = Roughness
1 - Flat
2 - Rolling
3 - Hilly
4 - Cliffs

Z = Geotechnical
1 - Good Thick
2 - Good Thin
3 - Bad

Code X	Y	Z	CE Values (Man-days)	Code X	Y	Z	CE Values (Man-days)	Code X	Y	Z	CE Values (Man-days)
1	1	1	5207.	3	1	1	6885.	5	1	1	11509.
1	1	2	5210.	3	1	2	6888.	5	1	2	11512.
1	1	3	9272.	3	1	3	10950.	5	1	3	15574.
1	2	1	8548.	3	2	1	10478.	5	2	1	15795.
1	2	2	8833.	3	2	2	10763.	5	2	2	16080.
1	2	3	11610.	3	2	3	13540.	5	2	3	18857.
1	3	1	13474.	3	3	1	15908.	5	3	1	22611.
1	3	2	14355.	3	3	2	16789.	5	3	2	23492.
1	3	3	15907.	3	3	3	18341.	5	3	3	25044.
1	4	1	25125.	3	4	1	28566.	5	4	1	38043.
1	4	2	32357.	3	4	2	35798.	5	4	2	45275.
1	4	3	26946.	3	4	3	30287.	5	4	3	39864.
2	1	1	6046.	4	1	1	8461.				
2	1	2	6049.	4	1	2	8464.				
2	1	3	10111.	4	1	3	12526.				
2	2	1	9513.	4	2	1	12290.				
2	2	2	9798.	4	2	2	12575.				
2	2	3	12575.	4	2	3	15352.				
2	3	1	14691.	4	3	1	18192.				
2	3	2	15572.	4	3	2	19073.				
2	3	3	17124.	4	3	3	20625.				
2	4	1	26845.	4	4	1	31795.				
2	4	2	34077.	4	4	2	39027.				
2	4	3	28666.	4	4	3	33616.				

APPENDIX O

CONSTRUCTION EFFORT VALUES FOR AN ASP-TYPE 2

Code:	X = Vegetation	Y = Roughness	Z = Geotechnical
	1 - Bare	1 - Flat	1 - Good Thick
	2 - Grass	2 - Rolling	2 - Good Thin
	3 - Brush	3 - Hilly	3 - Bad
	4 - Forest	4 - Cliffs	
	5 - Jungle		

Code X	Code Y	Code Z	CE Values (Man-days)	Code X	Code Y	Code Z	CE Values (Man-days)	Code X	Code Y	Code Z	CE Values (Man-days)
1	1	1	10494.	3	1	1	11533.	5	1	1	13391.
1	1	2	10494.	3	1	2	11533.	5	1	2	13391.
1	1	3	11492.	3	1	3	12531.	5	1	3	14389.
1	2	1	11021.	3	2	1	12215.	5	2	1	14353.
1	2	2	11096.	3	2	2	12290.	5	2	2	14428.
1	2	3	11592.	3	2	3	12786.	5	2	3	14924.
1	3	1	11459.	3	3	1	12965.	5	3	1	15660.
1	3	2	11713.	3	3	2	13219.	5	3	2	15914.
1	3	3	11852.	3	3	3	13358.	5	3	3	16053.
1	4	1	14079.	3	4	1	16208.	5	4	1	20019.
1	4	2	16253.	3	4	2	18382.	5	4	2	22193.
1	4	3	14398.	3	4	3	16527.	5	4	3	20338.
2	1	1	11013.	4	1	1	12257.				
2	1	2	11013.	4	1	2	12257.				
2	1	3	12011.	4	1	3	13255.				
2	2	1	11618.	4	2	1	13048.				
2	2	2	11693.	4	2	2	13123.				
2	2	3	12189.	4	2	3	13619.				
2	3	1	12212.	4	3	1	14015.				
2	3	2	12466.	4	3	2	14269.				
2	3	3	12605.	4	3	3	14408.				
2	4	1	15144.	4	4	1	17693.				
2	4	2	17318.	4	4	2	19867.				
2	4	3	15463.	4	4	3	18012.				

APPENDIX P

CONSTRUCTION EFFORT VALUES FOR A LSA

Code:

X = Vegetation
1 - Bare
2 - Grass
3 - Brush
4 - Forest
5 - Jungle

Y = Roughness
1 - Flat
2 - Rolling
3 - Hilly
4 - Cliffs

Z = Geotechnical
1 - Good Thick
2 - Good Thin
3 - Bad

Code			CE Values (Man-days)	Code			CE Values (Man-days)	Code			CE Values (Man-days)
X	Y	Z		X	Y	Z		X	Y	Z	
1	1	1	1283.	3	1	1	1574.	5	1	1	2094.
1	1	2	1291.	3	1	2	1582.	5	1	2	2102.
1	1	3	2930.	3	1	3	3221.	5	1	3	3741.
1	2	1	2645.	3	2	1	2979.	5	2	1	3578.
1	2	2	2736.	3	2	2	3070.	5	2	2	3669.
1	2	3	3345.	3	2	3	3679.	5	2	3	4278.
1	3	1	7002.	3	3	1	7424.	5	3	1	8178.
1	3	2	7881.	3	3	2	8303.	5	3	2	9057.
1	3	3	7795.	3	3	3	8217.	5	3	3	8971.
1	4	1	81169.	3	4	1	81765.	5	4	1	82832.
1	4	2	99305.	3	4	2	99901.	5	4	2	100968.
1	4	3	83023.	3	4	3	83619.	5	4	3	84686.
2	1	1	1428.	4	1	1	1777.				
2	1	2	1436.	4	1	2	1785.				
2	1	3	3075.	4	1	3	3424.				
2	2	1	2812.	4	2	1	3213.				
2	2	2	2903.	4	2	2	3304.				
2	2	3	3512.	4	2	3	3913.				
2	3	1	7213.	4	3	1	7718.				
2	3	2	8092.	4	3	2	8597.				
2	3	3	8006.	4	3	3	8511.				
2	4	1	81467.	4	4	1	82181.				
2	4	2	99603.	4	4	2	100317.				
2	4	3	83321.	4	4	3	84035.				

APPENDIX Q

CONSTRUCTION EFFORT VALUES FOR AN AAFS

Code: X = Vegetation
1 - Bare
2 - Grass
3 - Brush
4 - Forest
5 - Jungle

Y = Roughness
1 - Flat
2 - Rolling
3 - Hilly
4 - Cliffs

Z = Geotechnical
1 - Good Thick
2 - Good Thin
3 - Bad

Code X	Y	Z	CE Values (Man-days)	Code X	Y	Z	CE Values (Man-days)	Code X	Y	Z	CE Values (Man-days)
1	1	1	278.5	3	1	1	534.8	5	1	1	1226.7
1	1	2	278.5	3	1	2	534.8	5	1	2	1226.7
1	1	3	291.8	3	1	3	548.1	5	1	3	1240.
1	2	1	121.3	3	2	1	416.1	5	2	1	1211.7
1	2	2	129.	3	2	2	423.8	5	2	2	1219.4
1	2	3	148.	3	2	3	442.8	5	2	3	1238.4
1	3	1	149.9	3	3	1	521.6	5	3	1	1524.8
1	3	2	169.8	3	3	2	541.5	5	3	2	1544.7
1	3	3	177.1	3	3	3	548.8	5	3	3	1552.
1	4	1	271.6	3	4	1	797.	5	4	1	2215.4
1	4	2	329.	3	4	2	854.4	5	4	2	2272.8
1	4	3	309.	3	4	3	834.4	5	4	3	2252.8
2	1	1	406.7	4	1	1	771.9				
2	1	2	406.7	4	1	2	771.9				
2	1	3	420.	4	1	3	785.2				
2	2	1	268.7	4	2	1	688.7				
2	2	2	276.4	4	2	2	696.4				
2	2	3	295.4	4	2	3	715.4				
2	3	1	335.7	4	3	1	865.3				
2	3	2	355.6	4	3	2	885.2				
2	3	3	362.9	4	3	3	892.5				
2	4	1	534.3	4	4	1	1283.				
2	4	2	591.7	4	4	2	1340.4				
2	4	3	571.7	4	4	3	1320.4				

APPENDIX R

CONSTRUCTION EFFORT VALUES FOR A MSR

Code:

X = Vegetation
1 - Bare
2 - Grass
3 - Brush
4 - Forest
5 - Jungle

Y = Roughness
1 - Flat
2 - Rolling
3 - Hilly
4 - Cliffs

Z = Geotechnical
1 - Good Thick
2 - Good Thin
3 - Bad

Code			CE Values (Man-days/ foot)	Code			CE Values (Man-days/ foot)	Code			CE Values (Man-days/ foot)
X	Y	Z		X	Y	Z		X	Y	Z	
1	1	1	0.186	3	1	1	0.202	5	1	1	0.230
1	1	2	0.186	3	1	2	0.202	5	1	2	0.230
1	1	3	0.326	3	1	3	0.342	5	1	3	0.370
1	2	1	0.349	3	2	1	0.367	5	2	1	0.400
1	2	2	0.360	3	2	2	0.378	5	2	2	0.411
1	2	3	0.415	3	2	3	0.433	5	2	3	0.466
1	3	1	0.561	3	3	1	0.584	5	3	1	0.625
1	3	2	0.596	3	3	2	0.619	5	3	2	0.660
1	3	3	0.591	3	3	3	0.614	5	3	3	0.655
1	4	1	1.057	3	4	1	1.089	5	4	1	1.147
1	4	2	1.384	3	4	2	1.416	5	4	2	1.474
1	4	3	1.063	3	4	3	1.095	5	4	3	1.153
2	1	1	.194	4	1	1	0.213				
2	1	2	.194	4	1	2	0.213				
2	1	3	.334	4	1	3	0.353				
2	2	1	.358	4	2	1	0.380				
2	2	3	.424	4	2	3	0.446				
2	3	1	.572	4	3	1	0.600				
2	3	2	.607	4	3	2	0.635				
2	3	3	.602	4	3	3	0.630				
2	4	1	1.073	4	4	1	1.112				
2	4	2	1.400	4	4	2	1.439				
2	4	3	1.079	4	4	3	1.118				

Multiply figure by 3.28 to get CE Values in man-days per meter.

APPENDIX S

CONSTRUCTION EFFORT VALUES FOR A CANTONMENT BLOCK

Code:

X = Vegetation	Y = Roughness	Z = Geotechnical
1 - Bare	1 - Flat	1 - Good Thick
2 - Grass	2 - Rolling	2 - Good Thin
3 - Brush	3 - Hilly	3 - Bad
4 - Forest	4 - Cliffs	
5 - Jungle		

One cantonment clock is 350 ft. X 350 ft. and contains space for 240 men

Code			CE Values (Man-days/ Block)	Code			CE Values (Man-days/ Block)	Code			CE Values (Man-days/ Block)
X	Y	Z		X	Y	Z		X	Y	Z	
1	1	1	35	3	1	1	57	5	1	1	101
1	1	2	35	3	1	2	57	5	1	2	101
1	1	3	145	3	1	3	170	5	1	3	215
1	2	1	106	3	2	1	134	5	2	1	186
1	2	2	111	3	3	2	139	5	2	2	191
1	2	3	182	3	2	3	211	5	2	3	262
1	3	1	200	3	3	1	236	5	3	1	301
1	3	2	215	3	3	2	251	5	3	2	316
1	3	3	215	3	3	3	251	5	3	3	316
1	4	1	533	3	4	1	584	5	4	1	675
1	4	2	699	3	4	2	750	5	4	2	841
1	4	3	592	3	4	3	643	5	4	3	735
2	1	1	44	4	1	1	74				
2	1	2	44	4	1	2	74				
2	1	3	158	4	1	3	187				
2	2	1	120	4	2	1	155				
2	2	2	125	4	2	2	160				
2	2	3	196	4	2	3	225				
2	3	1	218	4	3	1	261				
2	3	2	233	4	3	2	277				
2	3	3	233	4	3	3	277				
2	4	1	558	4	4	1	620				
2	4	2	724	4	4	2	786				
2	4	3	618	4	4	3	679				

8.2 blocks per 1000 ft. X 1000 ft. square
5.5 blocks per 250 meter X 250 meter square

APPENDIX T

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